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THE LESSER MIGRATORY LOCUST

GLENN W. HERRICK and C. H. HADLEY, Jr.

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THE LESSER MIGRATORY LOCUST

(*Melanoplus atlanis* Riley)

Order, *Orthoptera* Family, *Acridiidae*

GLENN W. HERRICK AND C. H. HADLEY, Jr.

INTRODUCTION

During the past two summers certain sections of New York State have suffered severely from the ravaging attacks of swarms of grasshoppers. The regions most subject to attack have been the sandy soils through the middle of the State from east to west and along the eastern boundary from Saratoga County north to Clinton County. There have, of course, been isolated outbreaks here and there in restricted localities, mainly in sandy areas.

The species of grasshopper predominant in these outbreaks is the lesser migratory locust (*Melanoplus atlanis* Riley). Other species of locusts have been found during the two seasons, but none of these have been seriously destructive.

It is of interest to note that all the outbreaks of the lesser migratory locust have been local. No extensive migrations or flights comparable with those of the Rocky Mountain locust during the seventies have taken place. The hordes of grasshoppers appearing in any one locality have apparently developed from eggs deposited in the vicinity.

The local character of the outbreaks, and the fact that the grasshoppers do not migrate far from their original breeding grounds, have an important bearing on the question of control. It is of much practical importance and satisfaction to know that if the grasshoppers are killed in any one locality this region will not be subject to another attack from invading swarms coming from other areas. Thus the farmers of any given locality may feel assured that their efforts in the control of the locusts in their immediate vicinity will not later be nullified by incoming hordes of these pests.

The seriousness of the situation in 1914 demanded an investigation of the outbreaks with the view of ascertaining more definitely the distribution, breeding habits, and life history of the lesser migratory locust, to the end that effective methods of control might be recommended. The results of these investigations, extending over the two seasons of 1914 and 1915, are given in the following discussion.

CLASSIFICATION AND SYNONYMY

The family Acridiidae (known as locusts, or short-horned grasshoppers), to which the lesser migratory locust belongs, constitutes a group of insects including most of the grasshoppers of serious economic importance. The species under discussion belongs to the genus Melanoplus, which according to Scudder (1898)[1] is the dominant genus of the family.

Serville (1831) founded the genus Calliptamus, placing in it the three species — *Acrydium sanguinipes*, *A. italicum*, and *A. morio*. Later (Scudder, 1878) the generic name was changed to *Caloptenus* by Burmeister on orthographic grounds. Several years later, Burmeister (1839) retained *C. italicus* alone of the original species in the genus, thus making it the type species. Stål (1873) called attention to the differences between the European form *C. italicus* and the North American species referred to the same genus, and showed that the latter was much more closely connected to Pezotettix. He then made Melanoplus a subgenus of Pezotettix, with *Acridium femur-rubrum* DeGeer as the type species. Riley (1875) separated the North American species from *C. femur-rubrum* and *C. spretus* on structural and color characters, and described it as *Caloptenus Atlanis*. His original description is as follows:

> *Caloptenus Atlanis* N. sp.— Length to tip of abdomen 0.70–0.85 inch; to tip of closed wings 0.92–1.05 inches. At once distinguished from *femur-rubrum* by the notched character of the anal abdominal joint in the male and by the shorter, less tapering cerci; also by the greater relative length of wings which extend, on an average, nearly one-third their length beyond the tip of the abdomen in the dried specimens; also by the larger and more distinct spots on the wings — in all which characters it much more closely resembles *spretus* than *femur-rubrum.* From *spretus,* again, it is at once distinguished by the smaller size, the more distinct separation of the dark mark running from the eyes on the prothorax and of the pale line from base of wings to hind thigh; also by the anal joint in the male, tapering more suddenly and by the two lobes forming the notch being less marked. From both species it is distinguished not only by its smaller size but by the deeper, more livid color of the dark parts, and the paler yellow of the light parts — the colors thus more strongly contrasting.
>
> Six males, 7 females from New Hampshire. Just as the typical *femur-rubrum* is at once distinguished from the typical *spretus* by the characters indicated; so *Atlanis,* though structurally nearer to *spretus,* is distinguished from it at a glance by its much smaller size and darker, more marbled coloring. The contrast is all the greater in the living specimens, and I have seen no specimens of *spretus* that at all approach it in these respects.

This species has been referred to in literature many times under various names. The following is the synonymy given by Scudder (1898):

1874 *Caloptenus spretus* Packard (not Walsh 1866).
1875 *Caloptenus Atlanis* Riley.
1876 *Caloptenus atlantis* Thomas.
1876 *Caloptenus femur-rubrum* Provancher.
1878 *Melanoplus devastator* Scudder (pars.)
1878 *Melanoplus atlantis* Scudder.
1881 *Melanoplus atlanis* Scudder.
1883 *Caloptenus bilituratus* Bruner.
1886 *Pezotettix atlanis* Hunt.
1889 *Melanoplus atlanis caeruleipes* Cockerell.

COMMON NAME

Besides the name *lesser migratory locust*, which is the generally accepted one now, this insect has been referred to under other common names.

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[1] Dates in parenthesis refer to "Literature cited," page 43.

Riley (1875) named it the *Atlantic migratory locust*, but later (1878) concluded to call it the lesser locust, " as the species is not confined to the Atlantic slope, and the term Atlantic might convey a wrong idea." Lugger (1895) refers to it as the *White Mountain locust*. It has also been spoken of as the *Atlantic locust*, the *lesser locust*, and the *lesser red-legged grasshopper*. The New York farmer generally terms it *red-leg*, not attempting to differentiate it from the ordinary red-legged grasshopper *M. femur-rubrum*.

DISTRIBUTION

This species is probably indigenous to the North American continent and is essentially an eastern species. It was at first thought to be an eastern variety of the notorious Rocky Mountain locust, *M. spretus*, and indeed is sometimes hardly to be distinguished from *M. spretus* owing to its wide range of variation.

M. atlanis has a wide distribution on the continent. In many States it has at times been so abundant as to constitute a most serious menace to crops. Often it is found with other species, mainly *M. femur-rubrum* and *M. spretus*, and secondary to them. But in the instances noted below, it was either alone or in so much greater abundance as to completely overshadow in destructiveness the other species present.

From very early times, records indicate that New England has suffered from the depredations of grasshoppers.. Although the specific name of the grasshoppers present is not mentioned in early accounts, Riley and other authorities have thought that *M. atlanis*, if not wholly responsible for these visitations, was to a considerable extent responsible. It seems quite probable that to this species may be laid the credit, or discredit, for the outbreaks cited. In various parts of New England the following years have been recorded as bad grasshopper years: 1743, 1746, 1749, 1754, 1797, 1816, 1821, 1871, 1874, 1875, 1876, 1877, 1882, 1885, 1889, 1896, and 1901. In 1889 the outbreak was so severe in New Hampshire that a bounty of one dollar per bushel of grasshoppers was offered by the State. Under this stimulus, so it is recorded (Marlatt, 1889), in one instance sixty bushels of grasshoppers were collected by means of a hopper-dozer from an oat field of three and one-half acres. Since 1901 there seem to have been no serious outbreaks of this species reported until 1913. In that year and the two succeeding years, especially in 1915, grasshoppers were very destructive in certain parts of New Hampshire, notably in the Connecticut Valley.

Outbreaks of the lesser migratory locust have not been confined to New England alone. Minnesota has often been visited by this species, which in 1891, 1893, 1902, 1910, 1911, and 1912 was unusually abundant in various parts of the State. From 1900 to 1903 much injury was reported in Montana. In 1908 and 1909 the locust was abundant in

Michigan. It is common in Nebraska, where it appeared in great numbers about 1896, and again in 1911 and 1912 in certain parts of the State. In 1910 much injury was reported from Colorado, and in 1911, 1912, and 1913 from Kansas. An outbreak occurred in Oklahoma in 1913.

This species is common in Canada, and at times the crops in various sections of Canada, and especially in Manitoba, have been devastated by the pest. Unusually severe outbreaks occurred during the years from 1893 to 1896 and from 1900 to 1904. More recently, from 1912 to 1915, there were outbreaks in Ontario and Quebec (Gibson, 1915).

With the possible exception of *M. femur-rubrum*, the species under discussion is the most widely distributed of the native grasshoppers. It has been reported in greater or less abundance from nearly all the States. It is also found in Mexico, and in southern Canada up into British Columbia.

OUTBREAKS IN NEW YORK

In times past New York State has had "grasshopper years" at varying intervals. The first definite record of the abundance of the species

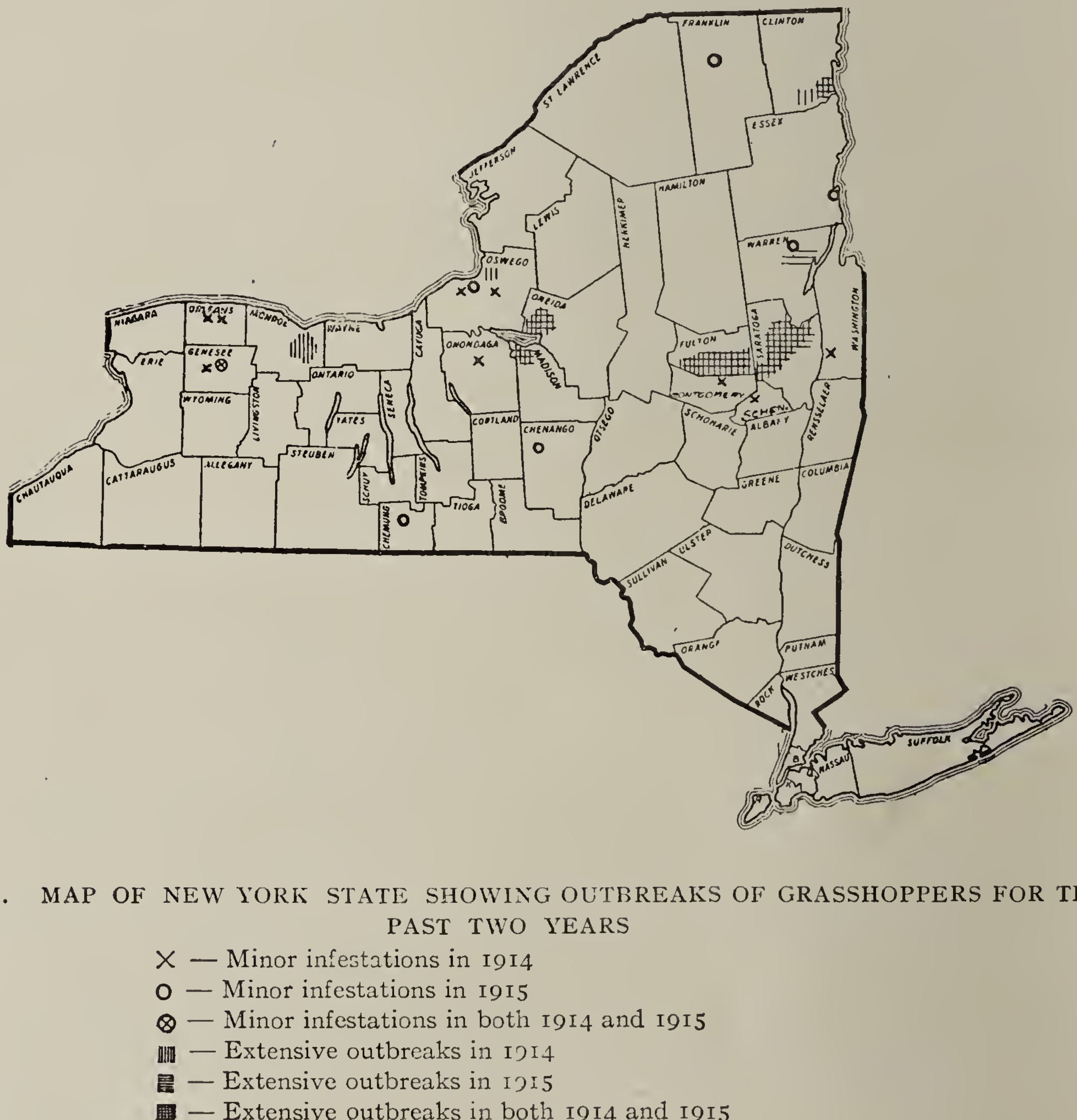


FIG. I. MAP OF NEW YORK STATE SHOWING OUTBREAKS OF GRASSHOPPERS FOR THE PAST TWO YEARS

× — Minor infestations in 1914
O — Minor infestations in 1915
⊗ — Minor infestations in both 1914 and 1915
▥ — Extensive outbreaks in 1914
▤ — Extensive outbreaks in 1915
▦ — Extensive outbreaks in both 1914 and 1915

M. atlanis is by Lintner (1895), who described the outbreaks of *M. atlanis* and *M. femur-rubrum* in 1893 and 1894. The western counties of the State appear to have suffered the most.

The seasons of 1912 and 1913 were very favorable for the multiplication of grasshoppers, and culminated in unusually severe outbreaks in 1914 and 1915. These outbreaks, although confined mostly to the more sandy areas of the State, caused a very considerable loss. The counties that suffered the most were Clinton, Warren, Saratoga, and Fulton. Minor outbreaks occurred also in the counties of Schenectady, Franklin, Oneida, Montgomery, Washington, Madison, Onondaga, Oswego, Monroe, Chemung, Chenango, Orleans, Essex, and Genesee (Fig. 1). In each case, while *M. atlanis* was the chief offender, other species were present in greater or less numbers.

CHARACTERISTICS OF THE REGIONS IN WHICH THE OUTBREAKS OCCURRED

Early in the investigation of the outbreaks of the lesser migratory locust, the writers were impressed with the fact that the regions in which the grasshoppers appeared in abnormal numbers are remarkably similar in soil, vegetation, kind of crops grown, and general type of farming, and in most of these respects these regions differ very markedly from closely surrounding sections. The soils are of a light sandy nature, of considerable depth and containing little humus. They are not suited for the growth of a wide variety of crops The regions are often characterized by sandy knolls and ridges, along the tops and sides of which the eggs of the grasshoppers were deposited in greater or less numbers. In some localities sand dunes are present, and occasionally these are so unstable as to take on the character of blowsand; in these sections the infestations of grasshoppers were less severe.

The crops grown in the regions of infestation appear to consist mainly of rye, oats, and corn. Wheat and potatoes are grown to a very limited extent in these general areas. The hay crop in most of the regions is sparse and is composed mostly of rather short, wiry grasses. Little fruit is produced in these sections. In certain sections, at least, abandoned farms are found, indicating the struggle for existence and the unproductive character of the soil.

The pastures on these light sandy soils are thin and bare, and the knolls and ridges form ideal breeding grounds for the grasshoppers. The hay-scented fern and the troublesome and annoying sand bur are familiar weeds among the scanty vegetation.

One is forced to the conclusion that here in these regions the grasshoppers find ideal conditions for the deposition and preservation of their eggs, and are thus able to make satisfactory provision for the increase and maintenance of the species. When the eggs hatch in the spring, the scanty vegetation and cereals grown afford enough food for the grasshoppers to reach maturity, although in many localities they consume nearly all the plant growth within their range.

FOOD PLANTS

It may be said with truth that the lesser migratory locust is almost omnivorous as far as plants are concerned. There seem to be but few of the commonly grown crops which it will not eat when available. The writers' observations of the last two years, however, seem to show that some crops are oftener devoured than others. Among those most generally attacked may be mentioned the following:

Rye.— Young rye plants are eaten down to the ground. After the plants have reached a height of six inches or so, the grasshoppers seem to attack them less; possibly the blades and the stalk have become tougher and are less palatable. When the kernels reach the milk stage the heads of the plants are eaten off, leaving only the bare straw (Plate I, 2). The writers have often seen half a dozen or more insects on a single head, late in the afternoon, feeding on the tender kernels.

Oats.— As in the case of rye, oats are completely devoured when the plants are small (Plates I, 1, and II, 1), and when full-grown the tender kernels are eaten out, leaving the stalks bare.

Clover.— When clover plants are small they are eaten down to the ground. When full-grown the succulent leaves are eaten, leaving only the veins and the stalks. All varieties of clover seem to suffer equally.

Alfalfa.— The writers have seen fields of alfalfa which were entirely destroyed, with nothing left but the bare stems.

Corn.— Corn is attacked especially when small, up to about six inches high. When the silk appears this is often eaten, thus preventing the forming of the ear.

Meadows and pastures.— As is to be expected, meadows and pastures suffer considerably, since they are usually the natural breeding places of the insects. In some cases they are stripped absolutely bare and remain so during the season. In the fall, after the grasshoppers have disappeared, the fields may make a feeble growth, but for all practical purposes they are ruined.

Many other crops are more or less severely damaged, the extent of the injury depending on the proximity of the locust swarms. In some cases they are entirely destroyed. Among the crops that belong in this class the writers have observed the following: apple — the foliage only is attacked; asparagus; beans; buckwheat — is attacked especially when small, practically the entire crop being killed; cabbage — especially young plants when first set out; melon — the leaves and tender stems are attacked; millet; peas; potatoes; quack grass; wheat.

In addition to the plants just named, the following have been mentioned in literature as being eaten by this species of grasshopper: barley; carrot; flax ("while plants are young"); garden vegetables ("all varieties of garden vegetables"); grasses; hay; hollyhock; hops; indian corn; muskmelon; onion; redtop ("reduced to mere unnutritive stalks"); squash; sugar beet; timothy ("reduced to mere unnutritive stalks"); tobacco ("eating leaves of young plants full of holes"); watermelon; wheat stubble.

At times the voraciousness of the insects leads them to devour substances that are hardly to be classed as food. The writers have often observed them clustered on fence rails, posts, tree trunks, and the sides of houses, gnawing the wood to such an extent as to make the gnawed places stand out in strong relief. This was especially noticeable on chill, cloudy, and rainy days, when the grasshoppers were inactive and remained massed together on their chosen resting places.

An interesting account of the lengths to which grasshoppers will go to satisfy their appetite is given by Harris (1862), who quotes from *Travels in New England and New York*, by Timothy Dwight. Although the name of the species concerned is not given, Riley and other authorities have thought that without doubt the passage referred to *M. atlanis*. Harris says:

> Bennington (Vermont), and its neighborhood, have for some time past been infested by grasshoppers (locusts) of a kind with which I had before been wholly unacquainted. . . . As I had no opportunity of examining them, I cannot describe their form or their size. Their favorite food is clover and maize. Of the latter they devour the part which is called the silk, the immediate means of fecundating the ear, and thus prevent the kernel from coming to perfection. But their voracity extends to almost every vegetable; even to the tobacco plant and the burdock. Nor are they confined to vegetables alone. The garments of laborers, hung up in the field while they are at work, these insects destroy in a few hours; and with the same voracity they devour the loose particles which the saw leaves upon the surface of pine boards, and which, when separated, are termed sawdust. The appearance of a board fence, from which the particles have been eaten in this manner, and which I saw, was novel and singular; and seemed the result, not of the operations of the plane, but of attrition.

LIFE HISTORY AND HABITS

THE EGG

The eggs are deposited by the female in a small pocket in the ground, and are cemented together into a mass or pod by a rather sticky viscid fluid which accompanies the discharge of each egg. The process of egg laying is discussed on page 20.

The size of the egg mass varies, depending on the number of eggs contained in the mass and the depth of the pocket when the eggs are laid.

Examination of a large number of masses in the spring and fall of 1915 showed the average length of the egg pods to be from $\frac{3}{4}$ to $1\frac{1}{8}$ inches, with the diameter of the egg mass proper from $\frac{1}{8}$ to $\frac{1}{4}$ inch and of the neck from 1/16 to 3/16 inch. The egg masses are rather gourd-shaped, with the neck more or less bent, as shown in figures 2 and 3.

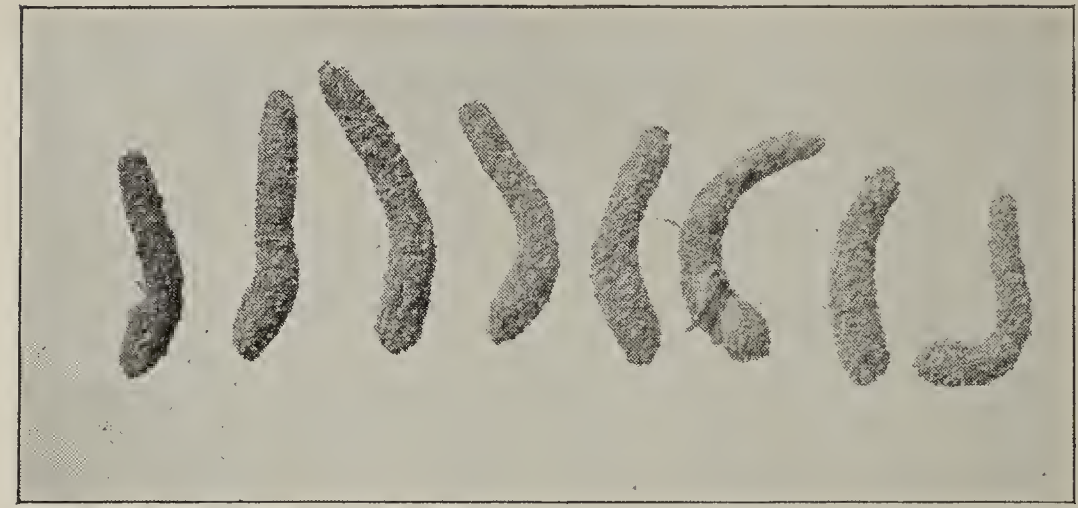


FIG. 2. EGG MASSES OF LESSER MIGRATORY LOCUST. NATURAL SIZE

There is usually considerable variation in the shape of the masses. The number of eggs in the mass also varies. An examination of eleven egg masses chosen at random contained 12, 13, 17, 5, 6, 13, 18, 15, 14, 9, and 13 eggs, respectively, with an average of about 12 eggs to a mass. Occasionally the first eggs deposited, which are located in the bottom or at the sides of the mass, are found to be crushed, as if from the pressure of the other eggs during the process of deposition.

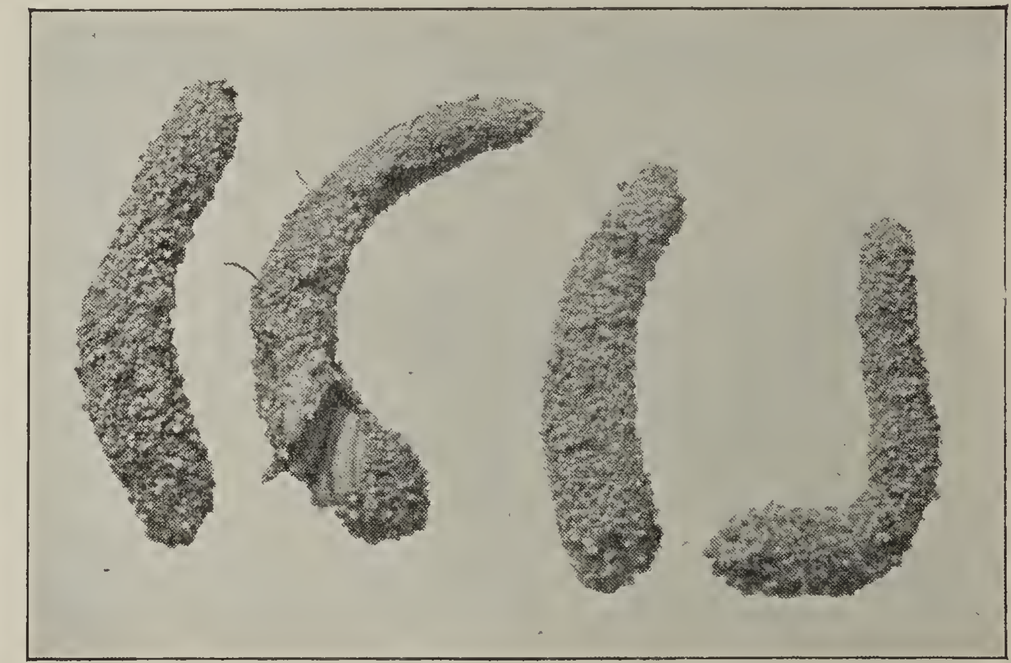


FIG. 3. EGG MASSES OF LESSER MIGRATORY LOCUST. ENLARGED 2 DIAMETERS

The following is a technical description of the egg:

Egg (mature, shortly before hatching).— Length from 4.3 to 4.4 millimeters, width at middle 1.2 millimeters. Somewhat shining; color faintly yellow, verging toward cream; no color markings. Shape sublinear, slightly curved on one side; anterior, or head, end bluntly rounded, posterior end more tenuately rounded. Shell punctate, or densely, finely, shallowly pitted. Pits not all regular in shape but approach hexagon, giving the appearance of a dense, fine network. Shell hard, thick, easily cracked by pressure. (Fig. 4.)

THE NYMPH

Although the eggs become mature in a short time after they are deposited in the late summer and early fall, as a rule they do not hatch until the following spring. There are occasional exceptions, which are discussed on page 23. In New York the eggs hatch in April or May, the exact time varying from year to year depending on the weather. In the spring of 1915 the writers first found young nymphs on April 24, near Saratoga, New York; they had been reported by correspondents, however, several days earlier. These nymphs, when examined in the field on that date, appeared to be several days old at least. A farmer in the vicinity claimed to have first seen the young grasshoppers in one of his fields on April 13 or 14. It is, of course, not absolutely certain that the young grasshoppers he noticed were the species *M. atlanis*, but there is no doubt that in favored localities these had hatched by the middle of April. By the first of May the writers had observed the young nymphs in several widely separated sections of the State. It is quite probable that in seasons when there is a mild spring, especially during the latter part of March, the grasshoppers hatch at any time during the month of April.

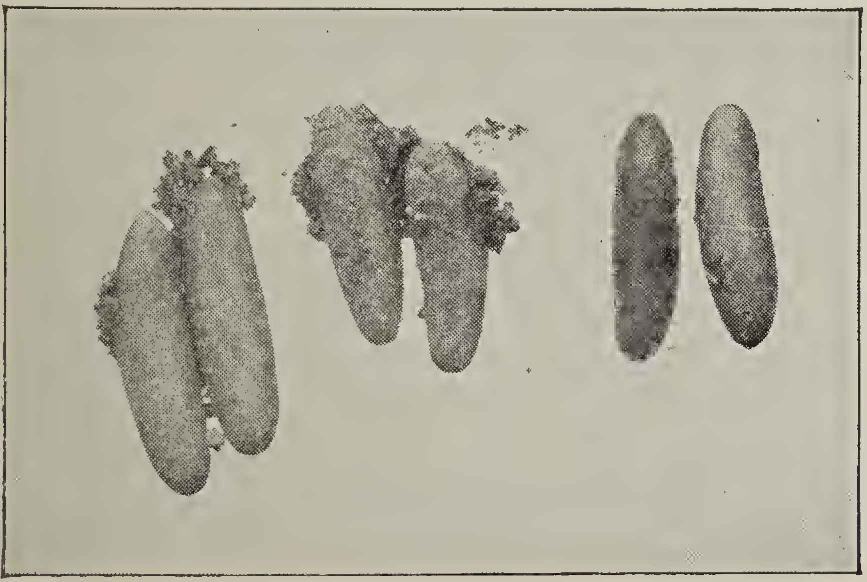


FIG. 4. EGGS OF LESSER MIGRATORY LOCUST. ENLARGED 5 DIAMETERS

All the eggs do not hatch simultaneously, the hatching period in a field extending over several days. In one field, where the young grasshoppers were well along in the first stage on April 25, unhatched egg masses were still rather common by the first of May. The hatching period may even extend through several weeks if conditions for hatching are unfavorable, as the writers observed in 1915. A period of cold or stormy weather after the first eggs have hatched will delay the hatching of the other eggs for a variable length of time. Riley (1878) has thought that the eggs laid earliest in the fall hatched first in the succeeding spring, and that since the egg-laying period in the fall may extend over a period of from six to eight weeks the hatching period may be similarly extended. There are no definite data to support this belief, but it is true that the period of hatching may cover a variable length of time, depending on circumstances.

The process of hatching has been observed by the writers in many cases and may be briefly described as follows: The egg cracks open at the head, or rounded end, and splits down the side toward the slightly pointed end. The young nymph, enveloped in the amnion, or embryonic coat, works its way out of the shell by convulsive movements of the body, and, when freed from the shell, casts off the amnion. (Plate III, 1.) Not until then is it able to extend the limbs. Within a very few minutes it is able to move and hop about freely. The whole process of hatching may be accomplished in a surprisingly short time. When first hatched the young nymph is quite pale and colorless, but within a few hours it acquires its characteristic mottled coloring.

From the time they are hatched the young nymphs are active and feed on green herbage in the vicinity (Plate II, 2). Usually food is abundant and their presence is not noticed for some time. Unless impelled by shortage of food or disturbed in some manner, the young nymphs do not travel to any extent, but walk or hop about, remaining in the same immediate vicinity. It often happens that food is plentiful enough so that the nymphs have reached the third or fourth stage before they spread out from their hatching ground enough to be noticed. In laboratory experiments the writers have found that newly emerged grasshoppers have gone without food for several days without noticeable discomfort. On cold or stormy days the grasshoppers do not feed, but remain huddled together among grass stems or weeds or in any convenient shelter. On bright days they congregate in open, sunny spots, feeding and moving about. At night they disappear, hiding away in the grass, under clods or stones, or in other places. During the late nymphal stages and at molting periods they crawl up grass stalks, fences, tree trunks, stumps, and the like. Their instinct seems to be to climb.

During the nymphal life these grasshoppers undergo five molts. It is not at all unusual to find cast skins hanging on blades of grass and similar places. Beginning with the third stage, just after the second molt, the rate of growth is very rapid, and there is considerable difference in size in the later stages. An abundant food supply naturally promotes faster growth, and continuous warm sunny days, especially during the later nymphal stages, also hasten the development of the insects. Under insectary conditions, with plenty of food and under apparently favorable conditions of temperature, the lengths of the different stages varied so greatly that it is impossible to make even an approximately general statement regarding them. Apparently opportunity for plenty of exercise, with abundant room to hop from place to place, is necessary for the proper development of the insects. An idea of the lengths of the respective stages may be obtained from table I, showing the collections made at Kirkville, New York, during the summer of 1915. Collections were made on the dates given, always on the same farm, where conditions seemed to be representative of the infested sections.

TABLE 1. COLLECTIONS AT KIRKVILLE IN 1915

Dates of collection	Number in first stage	Number in second stage	Number in third stage	Number in fourth stage	Number in fifth stage	Number in adult stage
May 7	205	1	......	......	......	......
May 13	26	142	......	......	......	......
June 4	......	......	15	77	7	......
June 7	......	5	35	293	79	......
June 15	......	......	24	......	463	41
June 26	3	3	2	10	64	184
July 6	......	......	......	3	22	118
July 22	......	......	2	1	7	212
July 30	......	......	......	1	5	347

After July 30 only an occasional fifth-stage nymph was found, most of the insects being adults. On August 25, in just one field, a few first- and fewer second-stage nymphs were found, and on October 25 twelve fifth-stage nymphs were found in this field. The field in question was situated in a very favorable location for early egg deposition, and without doubt some of the earliest eggs hatched late in the summer.

Taking as a basis the observations of the past season (1915) at Kirkville, it may be concluded that the lengths of the nymphal stages are approximately as follows:

Date of hatching approximately April 26

First nymphal stage	11 days
Second nymphal stage	16 days
Third nymphal stage	14 days
Fourth nymphal stage	10 days
Fifth nymphal stage	8 days

This is, of course, only an estimate, and it can readily be seen that several factors must be taken into consideration, such as temperature, climatic conditions, and so on. The actual time of transformation from nymph to adult is variable, as may be seen by table 1.

Observations at Kirkville showed that on June 11 no adults were to be found; on June 15 adults were scattering, and on June 21 they were abundant; by June 25, the majority of the insects found were winged. Observations at Peru, Clinton County (in the extreme northeastern corner of the State), showed that on June 22 a large proportion of the grasshoppers of this species, *M. atlanis*, were winged. In general, then, it may be said that the insects become fully grown about the middle of June. This is a rather important point in considering control measures, as is more fully brought out in the discussion of that subject (page 27).

The following is a technical description of the nymphal stages:

First stage.— When first hatched, rather light in color, without definite markings, soon becoming dull grayish brown, dotted with black, giving somewhat of a mottled appearance. Hind thighs dark, with more or less distinct pale crossbars on both inner and outer surfaces. Sometimes a distinct light line along median dorsal line of head and continuing along thorax. Antennæ 12-jointed, the first, second, third, eighth, and twelfth joints each about twice as long as any of the others; the second joint distinctly cup-shaped. No trace of wing pads. Length 4 to 5 millimeters. (Plate III, 2.)

Second stage.—In general, slightly lighter in color than in preceding stage. Crossbars on hind thighs broader and more distinct; relative sizes of light and dark areas varying in individuals. Ventral part of abdomen much lighter than remainder of body. A subquadrate mark behind the eyes, extending somewhat across the prothorax, rather distinct; a pale, more or less crescent-shaped, streak at lower margin of this black mark, extending part way across prothorax. Antennæ 15-jointed, joints 3, 7, and 8 of first stage having divided. No indications of wing pads except slight thickening and projecting of posterior lateral angles of mesonotum and metanotum. Length 6 to 8 millimeters. (Plates III, 3, and IV, 1.)

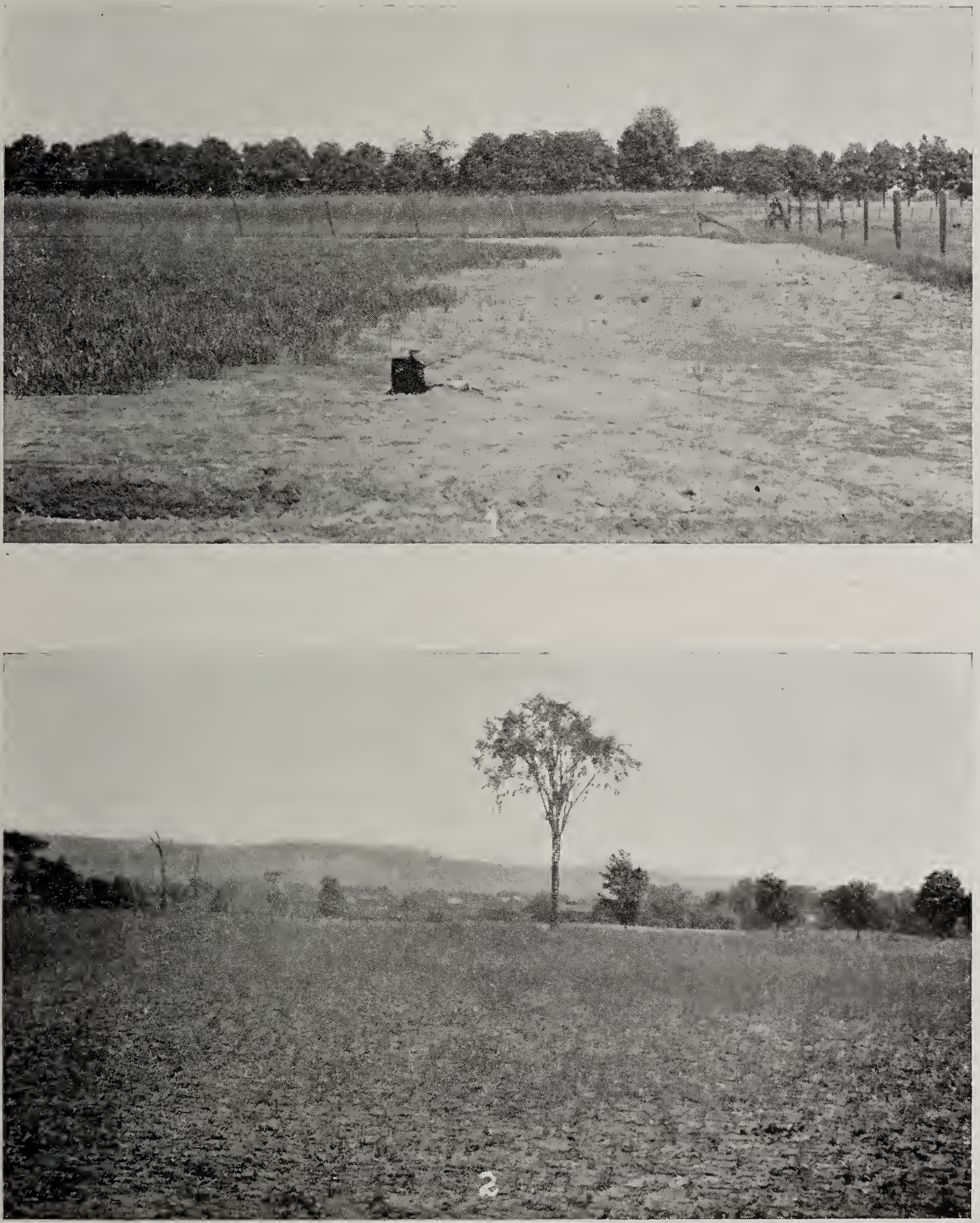
Third stage.— Distinctive markings of previous stages more pronounced. Body color in general the same, except ventral side of abdomen, which is pale yellow with a slight greenish tinge. Antennæ 17–18-jointed. Wing pads indicated by increased projection of posterior lateral angles of mesonotum and metanotum, now very pronounced. Length 9 to 12 millimeters. (Plates III, 4, and V, 2.)

Fourth stage.— True wing pads present, projecting obliquely upward and backward, with tips of hind pair reaching to middle of or slightly beyond middle of first abdominal segment. A conspicuous round white or silver spot near the middle of each of the hind wing pads. Dorsal surface of body, especially thorax, very dark. Sometimes dorsal or inner margins of both wings pale. Fore wings about one-third as long as hind wings. A black band running from back of eyes to ventral margin of prothorax meeting wing pad, very dark and conspicuous; also a light-colored crescent-like mark just below. Antennæ 20–21-jointed. Length 13 to 15 millimeters. (Plate IV, 2.)

Fifth stage.— Wing pads large, the outer reaching beyond posterior margin of second abdominal segment. Silver spot in hind wing generally conspicuous, in central part of basal third of wing, slightly removed from margin of attachment, surrounded by narrow black area, from which veins run out through remainder of wing. Inner margins of wings often pale. Fore and hind wings equal in length. A more or less distinct light streak along median dorsal line of thorax. Antennæ 23–24-jointed. Length 16 to 20 millimeters. (Plate IV, 3.)

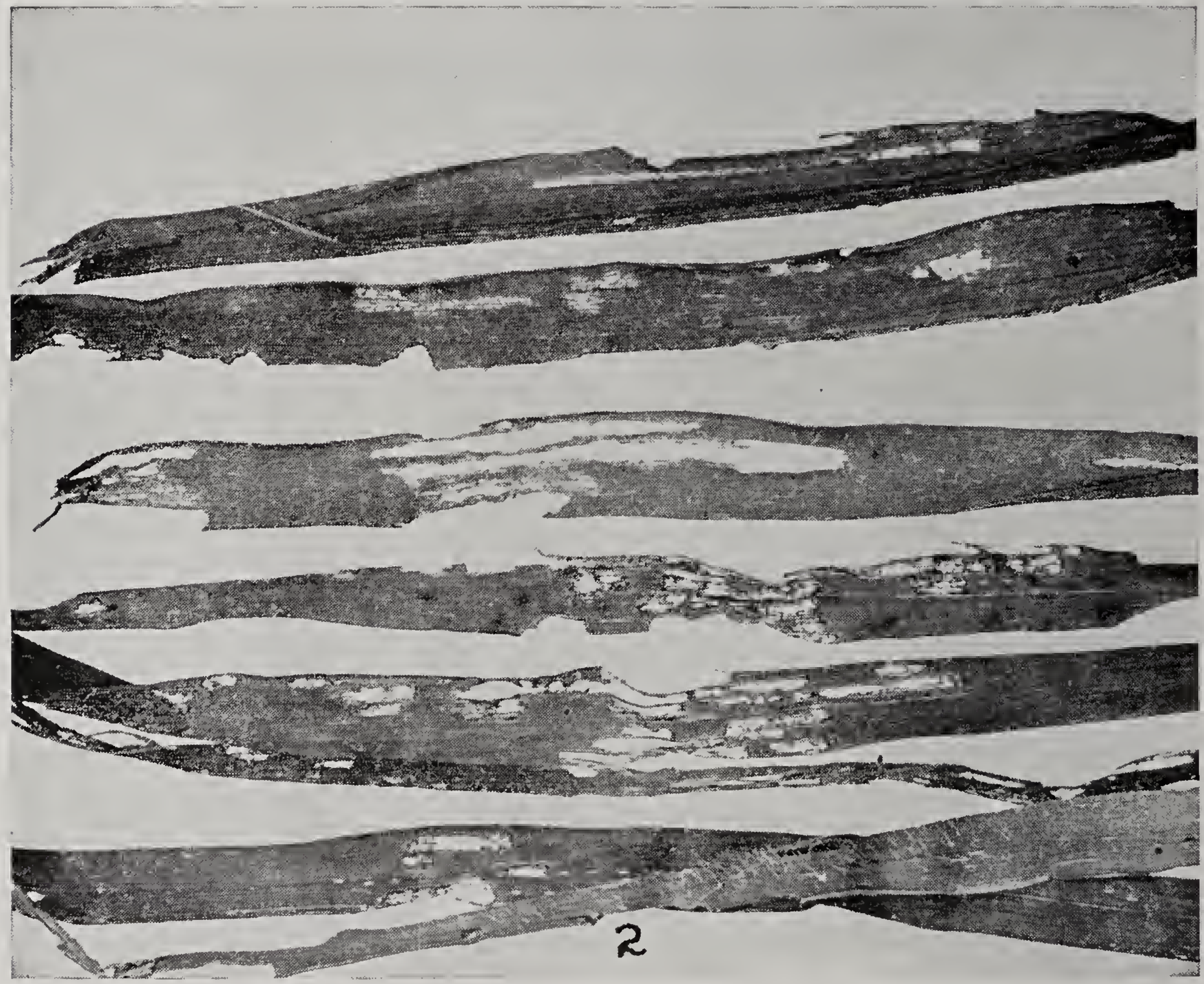
THE ADULT

The transformation from nymph to adult is the last stage in the development of the insect. When ready to transform, the nymph usually climbs up some erect object, where it remains for some time before molting takes place. During the latter part of June the cast skins of fifth-stage nymphs are very commonly found, the head end pointing downward, attached to blades of grass, stalks and heads of wheat and rye, fence posts, and similar objects. The actual process of molting, or shedding the skin, requires only a few minutes and usually takes place during the warmer part of the morning. The newly emerged adult soon dries off and is then ready for further activity.



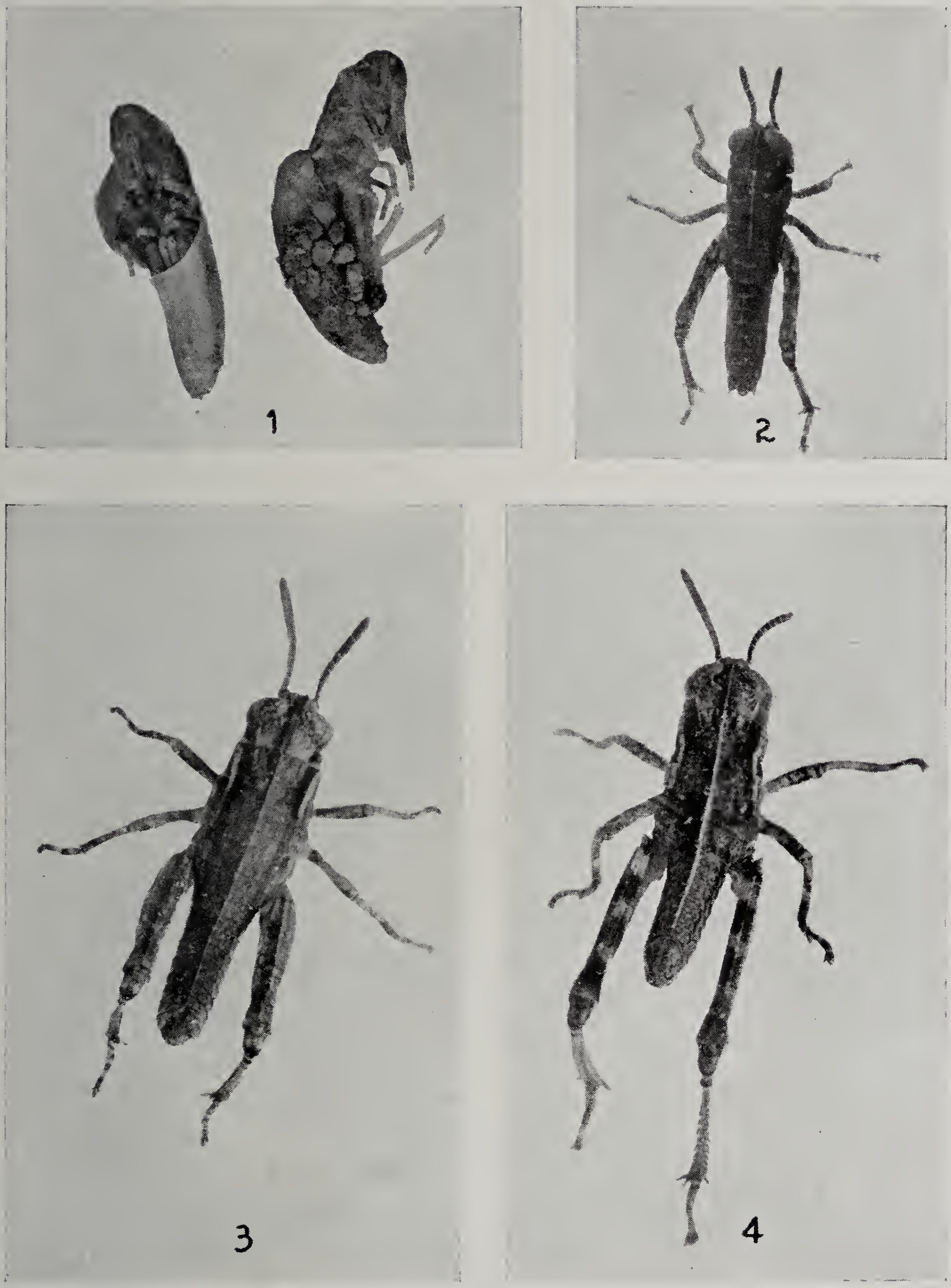
FIELDS ATTACKED BY THE LESSER MIGRATORY LOCUST

1, Oat field, showing how the locusts work inward from the edges
2, Field of rye after an attack by locusts

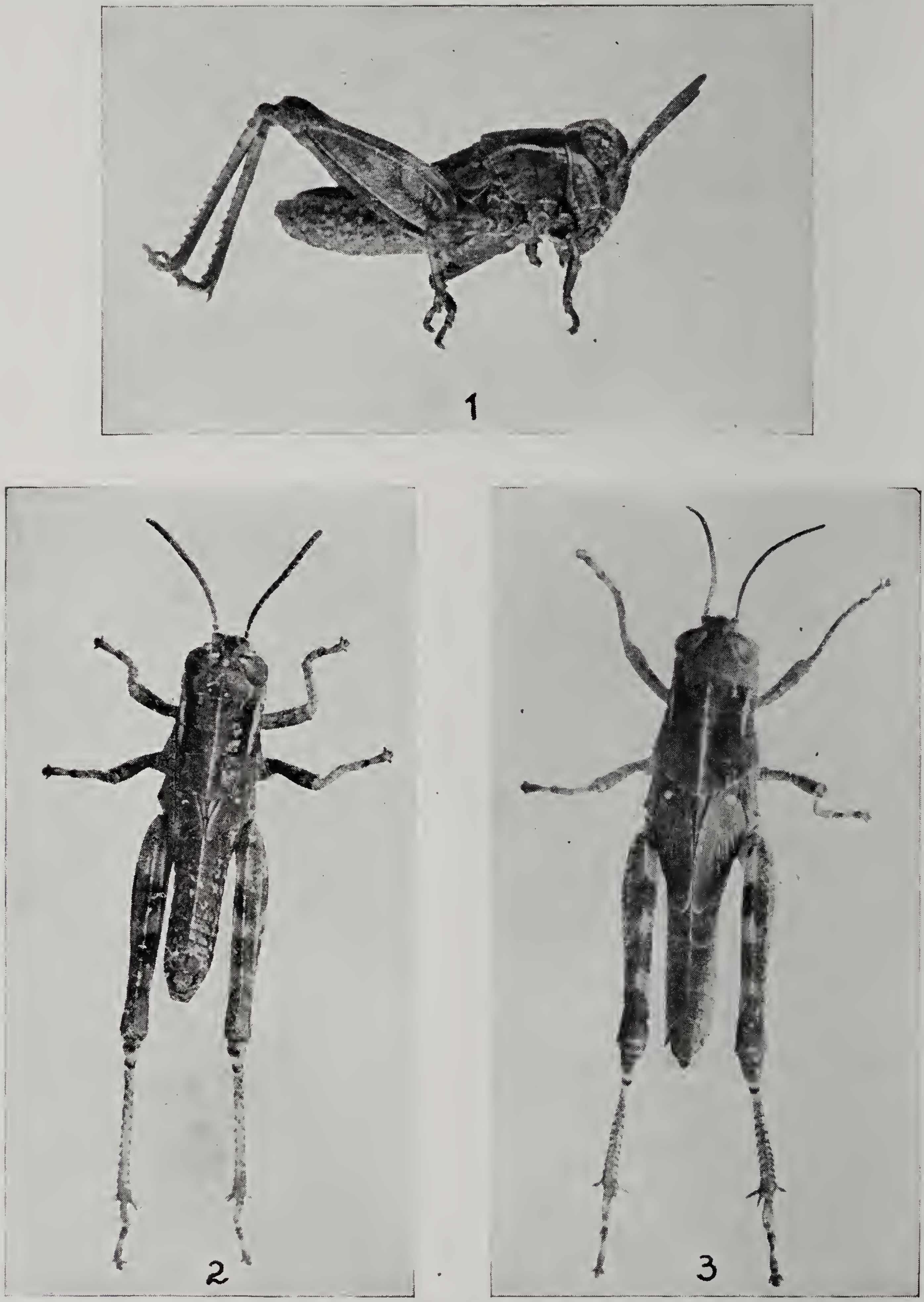


INJURIES CAUSED BY LOCUSTS

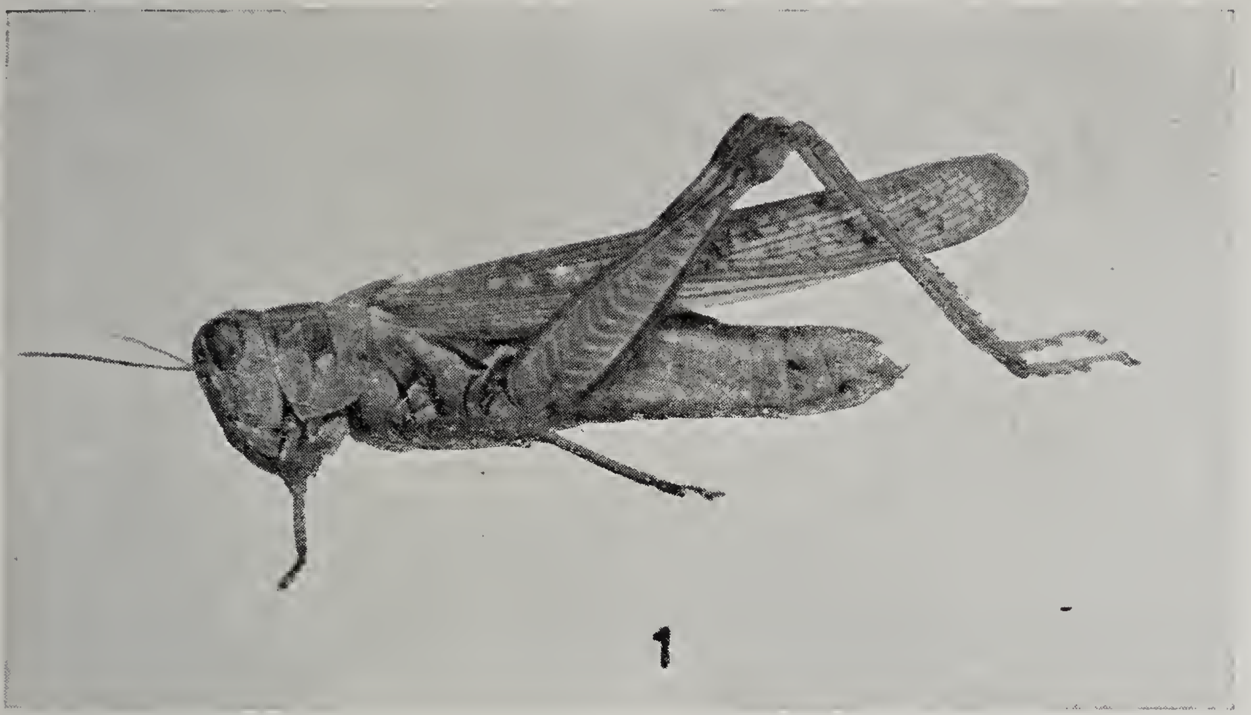
1, Oat field in which the locusts have just begun to feed
2, Injury to grass leaves caused by young locusts

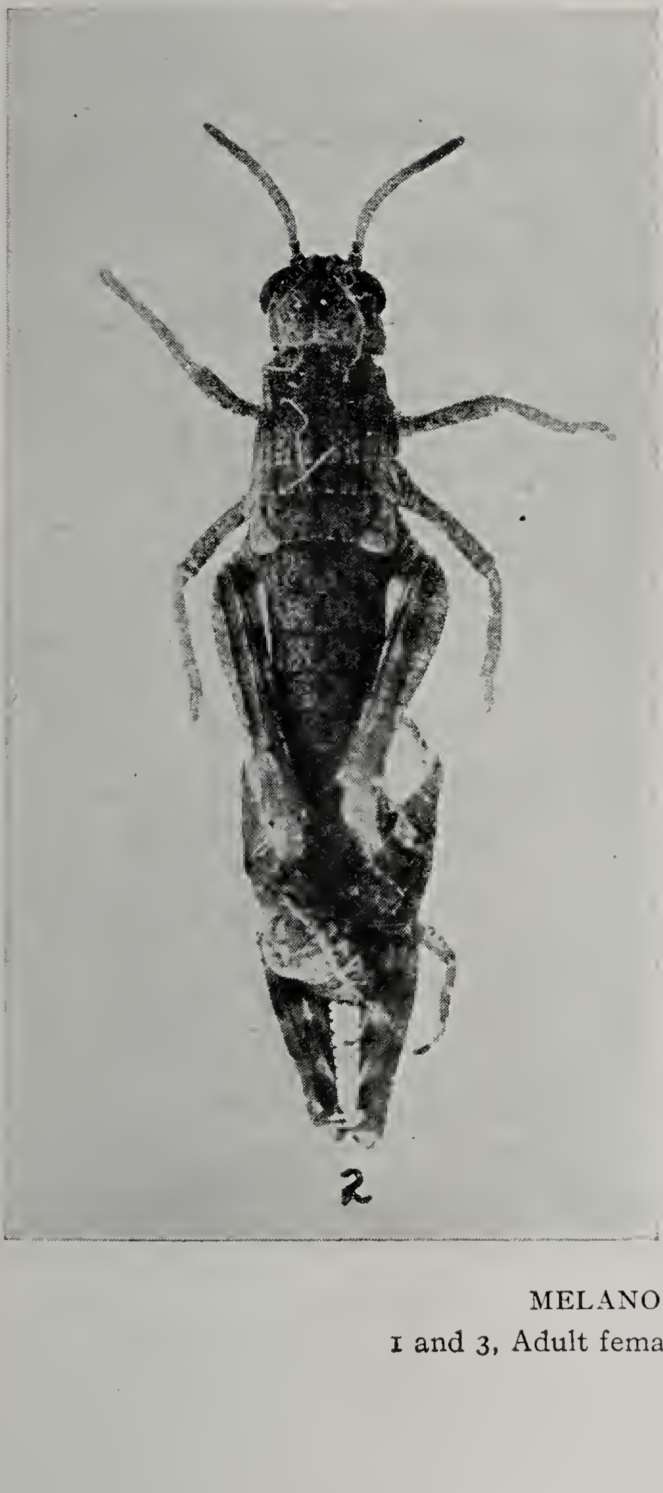


MELANOPLUS ATLANIS
1, Eggs hatching; 2, first-stage nymph; 3, second-stage nymph; 4, third-stage nymph



MELANOPLUS ATLANIS
1, Second-stage nymph; 2, fourth-stage nymph; 3, fifth-stage nymph


1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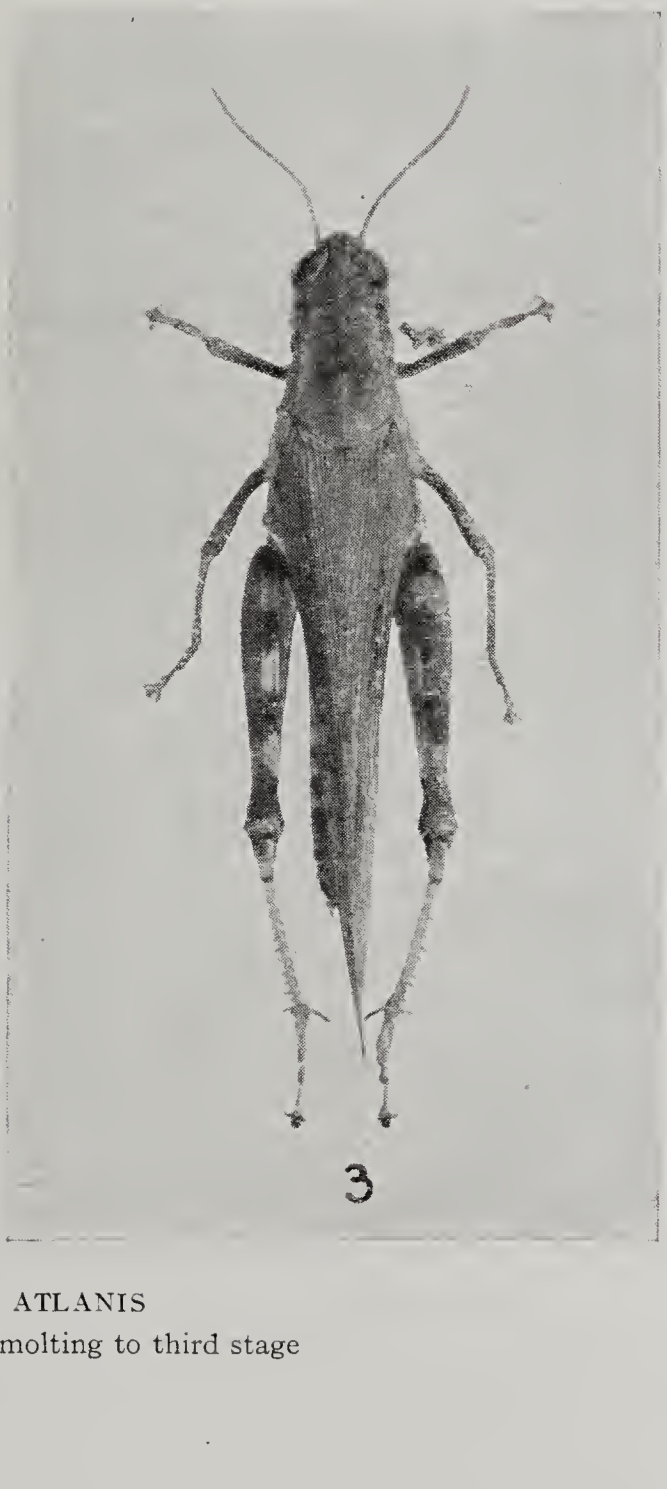
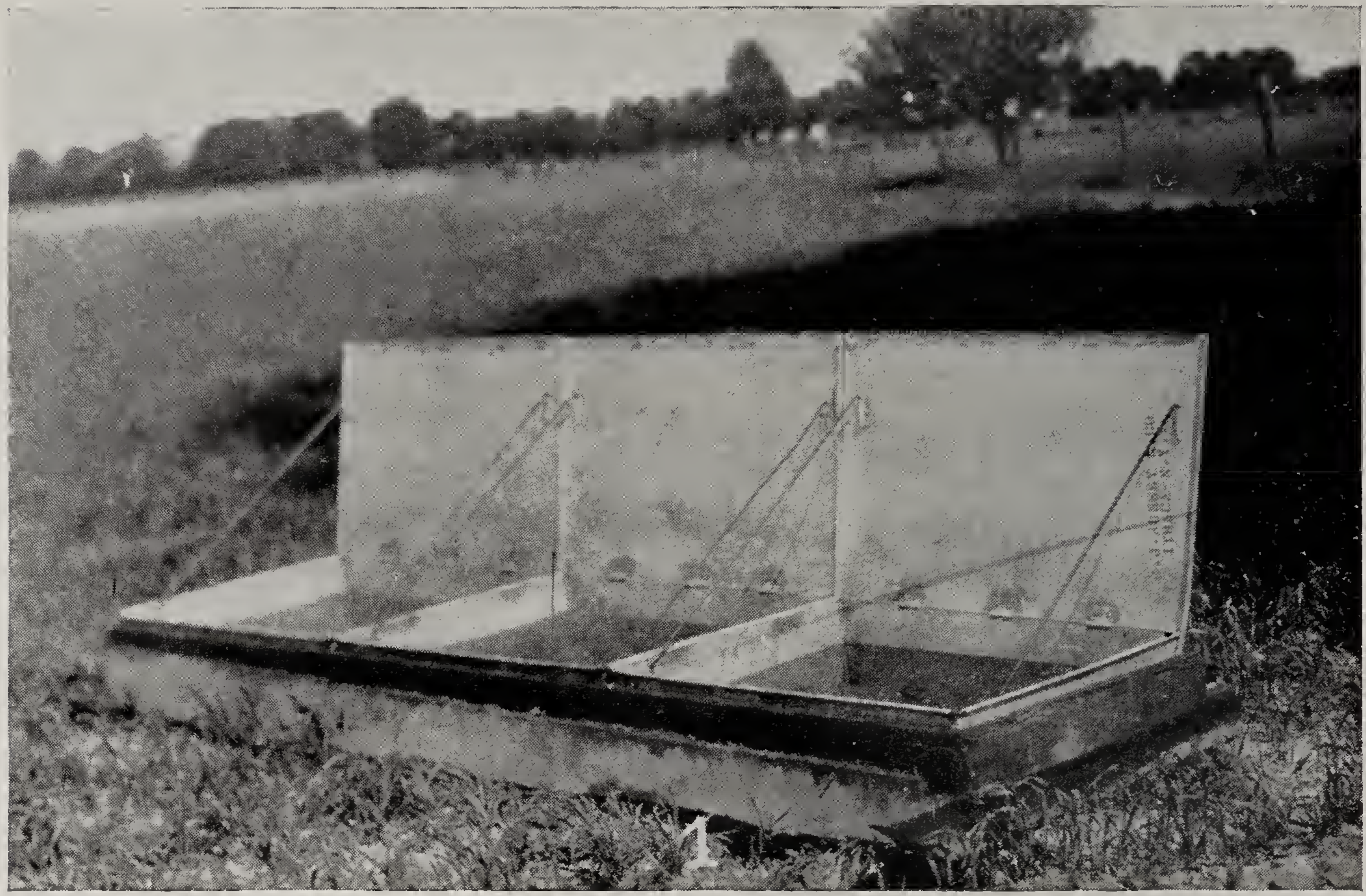
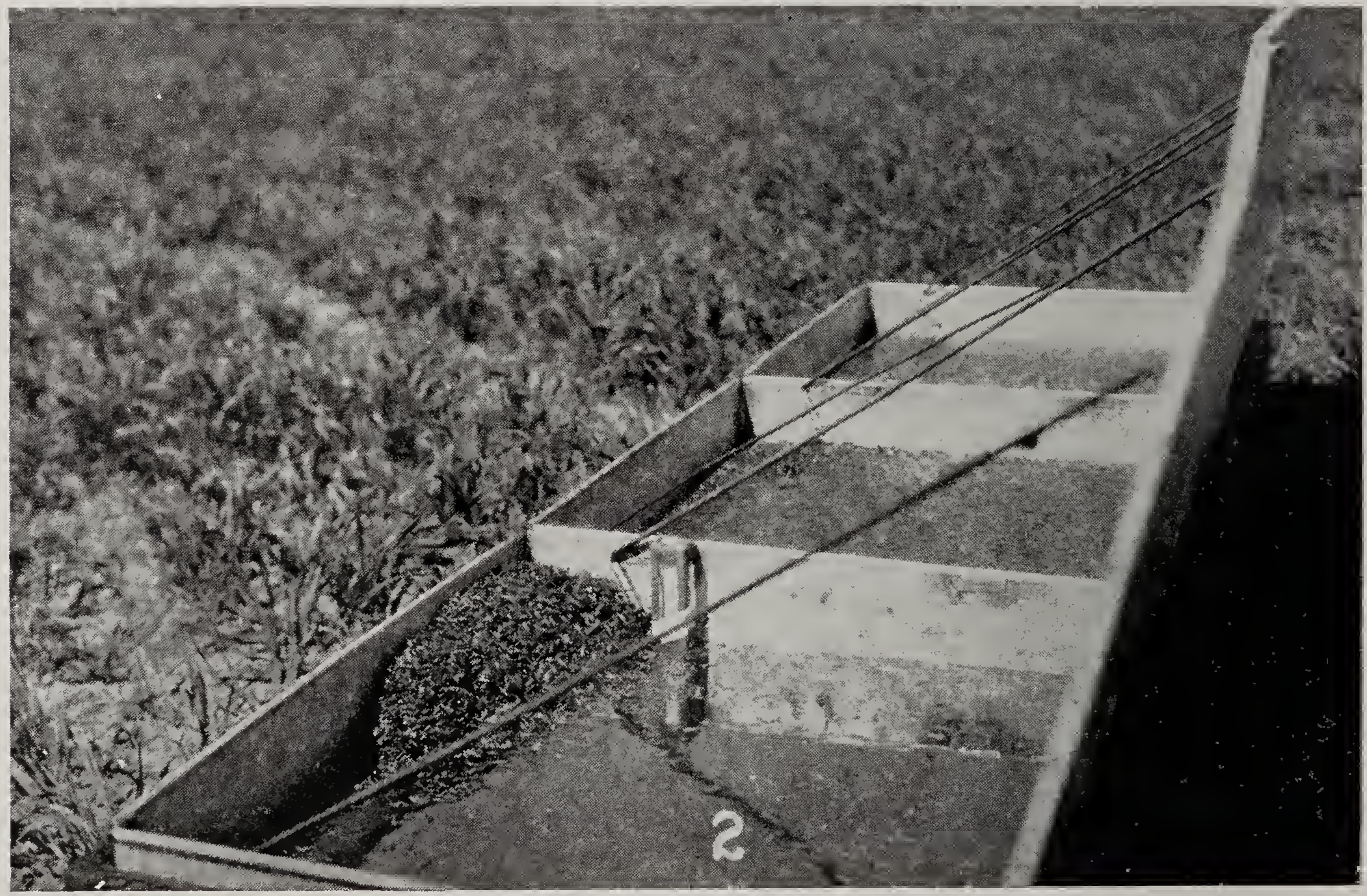

3

MELANOPLUS ATLANIS
1 and 3, Adult female; 2, molting to third stage





HOPPER-DOZER USED IN EXPERIMENTS

1, Front view of apparatus; 2, three gallons of grasshoppers caught in the first fifteen minutes

The adult grasshopper is a comparatively small insect, about an inch in length (Fig. 5), and is of a general yellowish or tan color. The femur of each hind leg has two distinct dark bars across the outer surface (Fig. 6). Late in the season the insects become somewhat darker in color, with a very slight olive tinge. The fore wings, which extend beyond the end of the body, are grayish in color, with a few distinct dark spots along the middle. This species may be readily distinguished from other common forms by the absence of any prominent markings other than those mentioned, and by its small size.

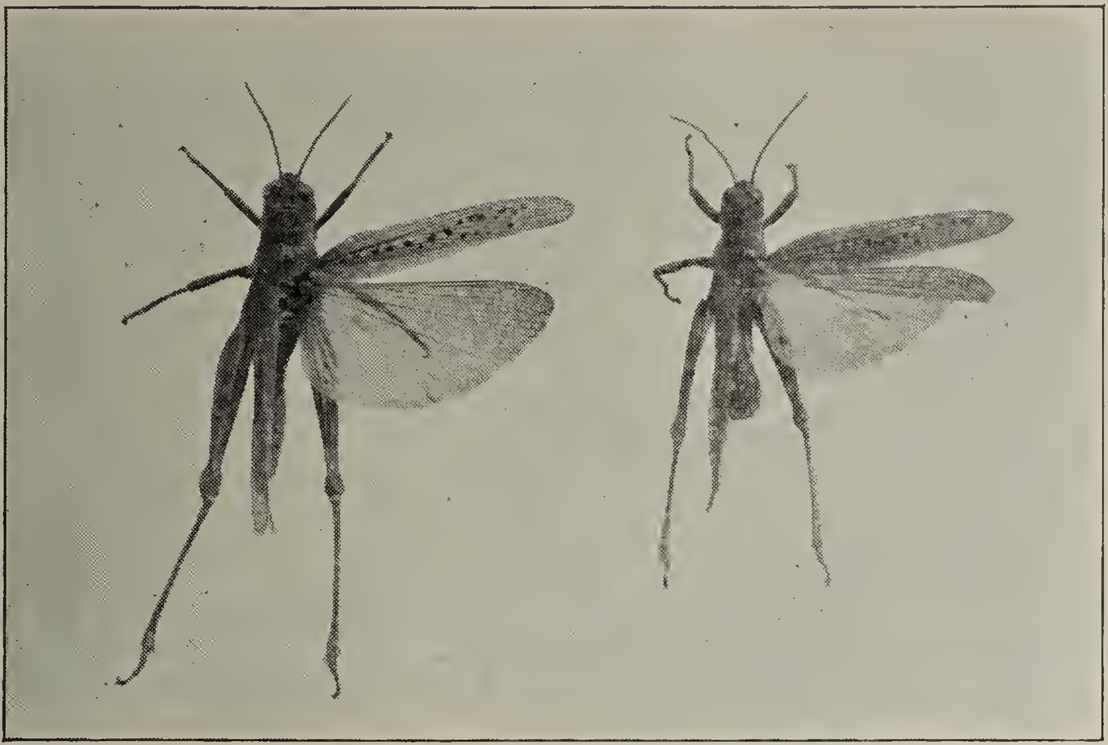


FIG. 5. THE LESSER MIGRATORY LOCUST (M. ATLANIS), FEMALE AND MALE. NATURAL SIZE

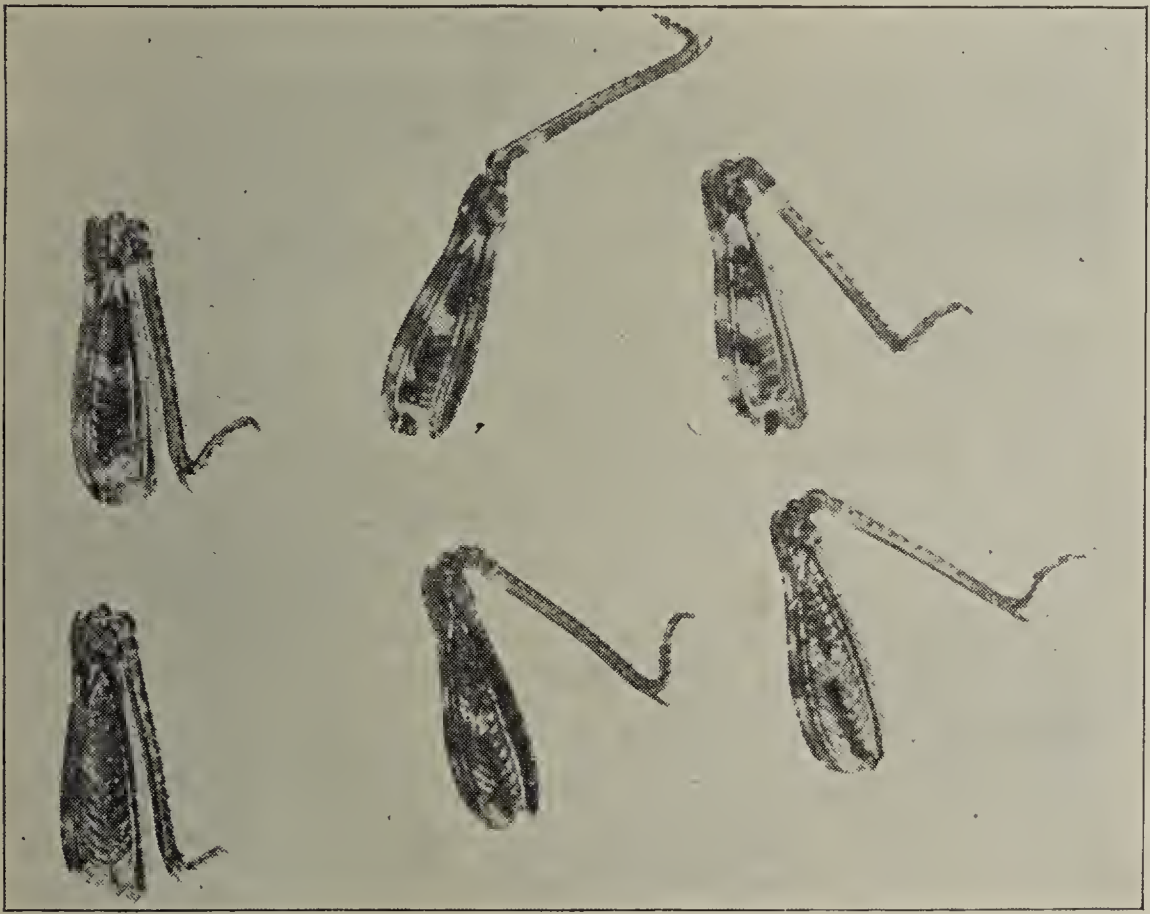


FIG. 6. VARIATIONS IN MARKINGS OF HIND FEMORA OF LESSER MIGRATORY LOCUST; OUTER FACE ABOVE, INNER FACE BELOW

The following is a technical description of the adult stage (Plate V, 1 and 3), as given by Blatchley (1903):

Size, medium. Vertex somewhat elevated above the pronotum, the interspace between the eyes nearly (male) or fully (female) twice as broad as the basal joint of antennæ; the front half strongly sloping, distinctly sulcate in the male, shallowly in the female. Frontal costa short, not reaching clypeus; feebly or not at all sulcate below the ocellus, the upper third a little narrowed. Antennæ three-fourths (male) or two-thirds (female) as long as hind femora. Pronotum rather short, distinctly expanding on the metazona, the disk flat or nearly so, the hind margin obtuse angled, the median carina distinct only on the metazona; the latter densely punctate and equaling the prozona in length. Tegmina fully developed, surpassing the hind femora. Extremity of male abdomen but little recurved; cerci about twice as long as broad, the apical half slightly upturned and somewhat inbent; the apex well rounded. Furcula consisting of a pair of moderately diverging slender, tapering spines, about one-third the length of the supra-anal plate. Sub-genital plate narrowing regularly from below upward, the apex somewhat thickened and elevated, and with a distinct median notch.

Color, either dark grayish or reddish brown. Head olive brown mottled with darker. The usual black band behind eye is confined to the prozona and in the reddish brown specimens and the females is often indistinct or broken into smaller spots. Tegmina grayish brown, flecked distinctly with fuscous along the discoidal area. Hind femora reddish yellow, with two oblique dark bars across the upper and outer facet; the lower face usually pinkish, the knees blackish, side of abdomen yellow.

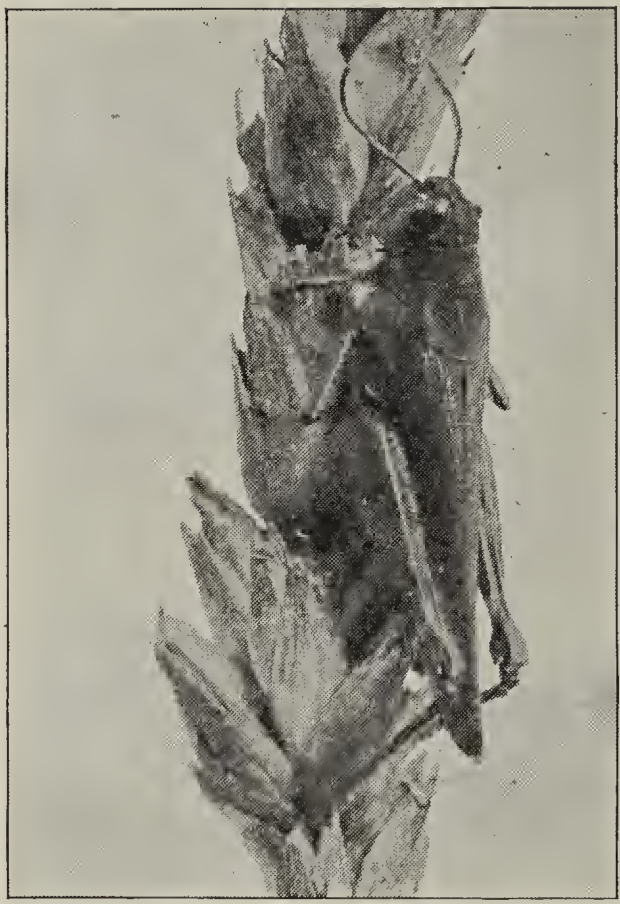


FIG. 7. LESSER MIGRATORY LOCUST ON WHEAT HEAD. ENLARGED

HABITS OF THE ADULT

In general most of the feeding is done in the middle of the day. If the day is cloudy or rainy, the grasshoppers remain huddled together in the grass, weeds, or other shelter, or they may crawl up any convenient object. On such days scarcely any feeding is done, but on bright sunny days the grasshoppers feed vigorously, hopping about restlessly. In the late afternoon they seek resting places, crawling upward wherever possible. The writers have seen them late in the afternoon clustered by the thousands on the walls of a shanty in a meadow. Ordinary rail fences enclosing a pasture lot offer a convenient place for congregating, and in thickly infested areas the fences may be almost entirely covered with the insects in the late afternoon. The writers have observed that rye and wheat fields also prove very attractive to grasshoppers, almost every stalk harboring several individuals. When the grain is in the milk stage the insects may do much damage while resting here by nibbling and gnawing the soft kernels in the head (Fig. 7).

Although they are strong flyers, the locusts of this species do not normally make any definite migration. In the field, when undisturbed, they travel by jumps and short flights, averaging possibly from fifteen to twenty feet in a single flight. When disturbed they will fly farther, and the writers have repeatedly seen them advance from eighty to one hundred feet in a single flight. As a general rule they fly at a height of from three to five feet above the ground, but on occasion they may fly higher.

During the season there is often a general drifting of a swarm in a more or less definite direction for a short distance. This habit was observed at Kirkville, New York. In 1914 the general movement of the swarm was westward, the insects drifting slowly from field to field during the summer. In the same section in 1915 the movement was back again, eastward. This is readily explained by the fact that as a result of the movement in 1914 most of the eggs were laid in the western part of the town. In 1915 the insects, hatching in great numbers in that section, slowly drifted eastward, moving from field to field for food. This movement is rather gradual, and sometimes, for some unexplainable reason, a field may be passed over unharmed or may be missed, although it apparently offers just as much attraction to the insects as a neighboring field which may be badly injured. The writers could not observe that in general the direction of the wind affected this movement to any appreciable extent. The same drifting movement has been observed at Gloversville, New York, and in other sections, but no definite migration or flight has taken place, such as was common among the swarms of the Rocky Mountain locust, *M. spretus*, in past years.

MATING

Early in July the insects commence mating. This was first observed at Kirkville in 1915 on July 6, when pairs were found *in copula* here and there. A farmer of that neighborhood told the writers that while distributing poison bait about the first of the month he had observed copulation taking place occasionally. It is safe to assume that mating begins very early in the month, depending largely on the weather and the earliness of the season. By the middle of the month the mating season was well under way. Many pairs were to be seen *in copula*, especially in the thinly covered meadows and pastures, where conditions were suitable for egg deposition, and along fence rows and roadsides. Mating continues for some time, pairs *in copula* having been found as late as the latter part of September. In a closely related species — the common red-legged locust, *M. femur-rubrum* — mating was observed at Ithaca, during a warm spell in the fall, as late as November 7.

EGG LAYING

The females commence laying eggs toward the middle of July and continue until cool weather sets in in the fall. In the summer of 1915, at Kirkville, egg masses were first found on July 30; in 1914 they were first found on July 27. An interesting point was noted in connection with the first egg masses found in 1914. Immediately after they were dug up some of the masses were placed in alcohol, and while they were in alcohol some of the eggs hatched, fully matured nymphs coming out from the shell. Packard (1883), in his studies on the embryology of *M. atlanis*, found that the embryo was fully developed in the egg ten days after deposition. Accepting Dr. Packard's finding, it may safely be assumed that egg laying begins shortly after the middle of July, at least. The actual date, of course, is largely dependent on local climatic conditions. As may be seen from table 2, the month of July in 1915, in the vicinity of Kirkville, was rather unfavorable for egg deposition, especially the first half of the month. Practically continuous cloudy and showery days undoubtedly helped to retard deposition of eggs. It is quite probable that in normal years the season for deposition would be well under way by the middle of the month.

The process of egg laying has been observed many times. The first part of the process may perhaps best be described by the following account by Riley (1878):

> The female, when about to lay her eggs, forces a hole in the ground by means of the two pairs of horny valves which open and shut at the tip of her abdomen, and which, from their peculiar structure, are admirably fitted for the purpose. With the valves closed she pushes the tip into the ground, and by a series of muscular efforts and the continued opening and shutting of the valves, she drills a hole, until in a very few minutes (the time varying with the nature of the soil) nearly the whole abdomen is buried. The abdomen stretches to its utmost for this purpose, especially at the middle, and the hole is generally a little curved, and always more or less oblique.

When the hole is completed to her satisfaction the female commences depositing her eggs in it, one by one. Each egg as it is laid is accompanied by a frothy, sticky fluid, which surrounds it and serves to hold all the eggs together in a compact mass. When the full complement of eggs is laid, the insect fills the remainder of the hole with the same frothy substance, which soon hardens, completely sealing the hole and effectually protecting the eggs from moisture. When the eggs are ready to hatch this material softens sufficiently to allow the young grasshopper to work its way up through when it has hatched.

THE EGG MASS

Contrary to what might be expected, the eggs are not thrust haphazard into the egg pocket, but are carefully arranged so that, at whatever angle the hole is made, they are in the position best adapted for the safe emergence of the young grasshopper. The blunt end of the egg always points upward and not directly in a line with the eggs above it, so that the young nymph has an unobstructed irregular path up through the neck of the egg mass to the surface of the ground. With this species there are generally from two to four or five layers of eggs in the mass.

The eggs are deposited, preferably, in more or less sandy soil, where the ground is fairly compact. The writers have found the egg masses generally laid in closely grazed pastures and meadows of long standing, where the

TABLE 2. CLIMATOLOGICAL DATA FOR 1915, FAYETTEVILLE, NEW YORK*

Day of month	March			April			May			June			July			August			September			October		
	Temperature (degrees Fahrenheit)		Rainfall (inches)	Temperature (degrees Fahrenheit)		Rainfall (inches)	Temperature (degrees Fahrenheit)		Rainfall (inches)	Temperature (degrees Fahrenheit)		Rainfall (inches)	Temperature (degrees Fahrenheit)		Rainfall (inches)	Temperature (degrees Fahrenheit)		Rainfall (inches)	Temperature (degrees Fahrenheit)		Rainfall (inches)	Temperature (degrees Fahrenheit)		Rainfall (inches)
	Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.	
1	35	9	.....	40	30	.....	50	40	.24	80	54	.....	78	62	1.01	87	66	.02	68	43	.....	66	40	.02
2	35	26	†T	36	28	.06	55	40	T	76	56	.....	80	60	1.61	87	69	.....	88	55	.....	55	45	1.18
3	28	12	T	36	16	T	55	36	.....	70	45	.....	82	60	.70	75	56	1.52	80	58	.....	62	45	......
4	32	3	.....	48	28	.....	58	34	.....	74	43	.....	78	60	.30	76	55	.04	80	62	.....	72	52	......
5	36	18	.....	40	29	T	56	40	T	78	46	.....	78	60	.36	80	59	.....	78	60	.....	64	48	1.20
6	34	27	.31	50	38	.06	72	45	.....	82	45	.....	70	52	T	78	60	.82	76	64	T	55	45	T
7	44	28	.....	51	37	.02	65	52	.06	85	64	.....	77	56	T	80	62	.39	78	62	.12	62	46	......
8	35	15	.....	62	38	.....	78	50	.64	78	52	.22	66	56	1.38	80	60	.37	87	64	.62	52	45	......
9	36	16	.....	70	42	.....	68	46	T	72	42	.23	72	50	.....	73	59	.06	88	67	.58	56	37	......
10	40	24	T	78	52	.06	68	30	.....	65	49	.....	81	56	.....	50	58	.....	82	70	T	47	37	.11
11	34	26	T	74	58	.05	76	37	.....	78	52	.06	80	60	.12	87	58	.....	78	62	T	67	36	......
12	34	8	.....	62	36	.06	74	56	.....	74	52	.03	78	56	.15	77	64	.33	80	54	T	80	48	......
13	44	20	.....	48	30	.....	64	42	.54	82	58	.....	84	62	.90	80	66	T	86	62	1.86	78	52	......
14	45	25	.....	56	26	.....	56	34	.....	78	64	T	85	60	.38	84	65	T	94	68	.71	70	60	.10
15	43	20	.....	64	28	.....	58	30	.....	74	58	.94	85	64	.....	80	66	.06	93	76	.66	68	54	.81
16	34	14	.....	56	34	.....	52	32	.09	78	62	T	86	60	.05	86	64	T	88	68	.32	58	46	......
17	30	16	T	56	35	T	52	40	.11	82	66	.....	82	70	.....	75	55	.26	72	65	.52	71	40	......
18	34	10	.....	58	26	.....	56	40	.....	84	50	.....	76	56	.02	70	43	.....	78	55	.....	62	48	T
19	46	18	.....	78	38	.....	58	38	.....	76	64	.42	82	58	.11	75	50	.....	76	60	.04	64	50	.67
20	36	25	T	70	45	.....	56	40	.....	64	52	.....	76	56	.....	80	58	.....	78	55	.....	70	52	......
21	34	28	.06	65	25	.....	60	50	T	66	45	.....	72	54	T	78	54	.28	72	52	.14	64	45	......
22	34	30	.14	64	46	.....	70	54	.34	76	52	.82	78	52	.....	72	62	.19	62	40	.....	56	41	......
23	53	30	T	66	54	T	68	50	T	60	50	.64	80	52	T	80	58	.58	70	40	.....	50	32	T
24	48	26	.....	79	56	.....	63	43	.....	67	50	.....	84	58	.....	82	60	.....	72	49	.....	45	32	......
25	46	34	.17	90	56	.....	72	42	.....	74	50	.32	82	65	.....	72	60	.....	70	48	.....	60	30	......
26	38	20	T	89	58	.....	64	46	.24	74	52	.....	75	62	.75	70	50	.....	66	46	.41	58	48	.10
27	34	16	.....	85	55	T	58	28	.....	72	50	.....	80	60	.....	72	40	.....	58	43	.....	58	48	......
28	42	26	.....	83	56	.16	62	37	.....	74	48	.....	75	62	.23	68	44	.....	59	33	.....	65	48	......
29	34	15	T	77	56	.14	67	36	.....	83	55	.....	80	64	T	68	58	.18	64	36	.....	60	45	.06
30	30	14	.02	56	40	T	70	35	.....	74	62	.84	84	68	T	66	54	T	68	37	.....	48	40	T
31	32	22	T	...	....	.....	74	40	.....	...	....	.....	85	67	T	62	50	.02	...	....	.....	62	30	......

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* From United States Weather Bureau records, New York section. Fayetteville is within a very few miles of Kirkville.

† Trace; an amount less than 0.01 inch, too small to be measured.

grass has become thin and especially along the edges of paths and furrows or shallow ditches running through such meadows. (Fig. 8.) The eggs are also deposited in undisturbed soil along lanes and roadways, and beside fences (Figs. 9 and 10.) Another favored location is along the crests and sides of sandy knolls. As a rule, cultivated fields are avoided for egg laying, although this is not invariably the case. In the fall of 1915 the writers found a field in which the egg masses averaged from five to seven per square foot, in spite of the fact that a fair crop of rye was taken from it that season. In general, however, it may be said that fairly compact, sandy soil which remains undisturbed by the plow is usually preferred for egg deposition. This is an important point, and is again touched upon in the discussion of control measures (page 27).

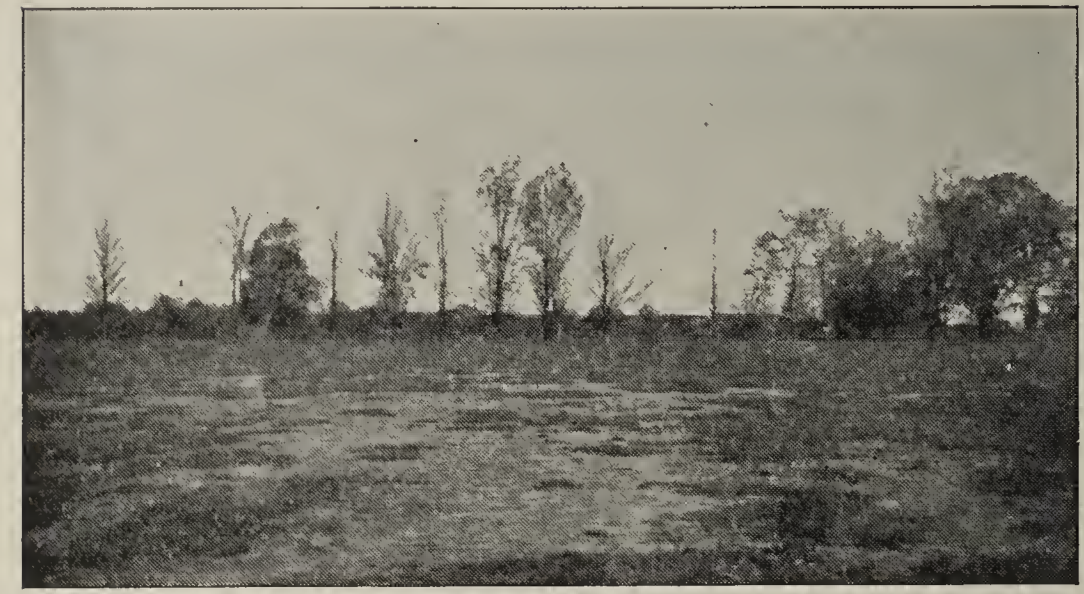

FIG. 8. SANDY FIELD, IN BARE PATCHES OF WHICH EGGS WERE LAID

The abundance of egg masses in a field will vary, as might be supposed, depending on the abundance of the insects in that field at egg laying time and on the type of soil. Fields and pastures examined by the writers in the early spring and fall of 1915 showed from one to as many as seven egg pods per square foot, with an average in the more heavily infested grasshopper sections of from three to four masses per square foot. This means that there were in round numbers approximately 125,000 egg masses to the acre.

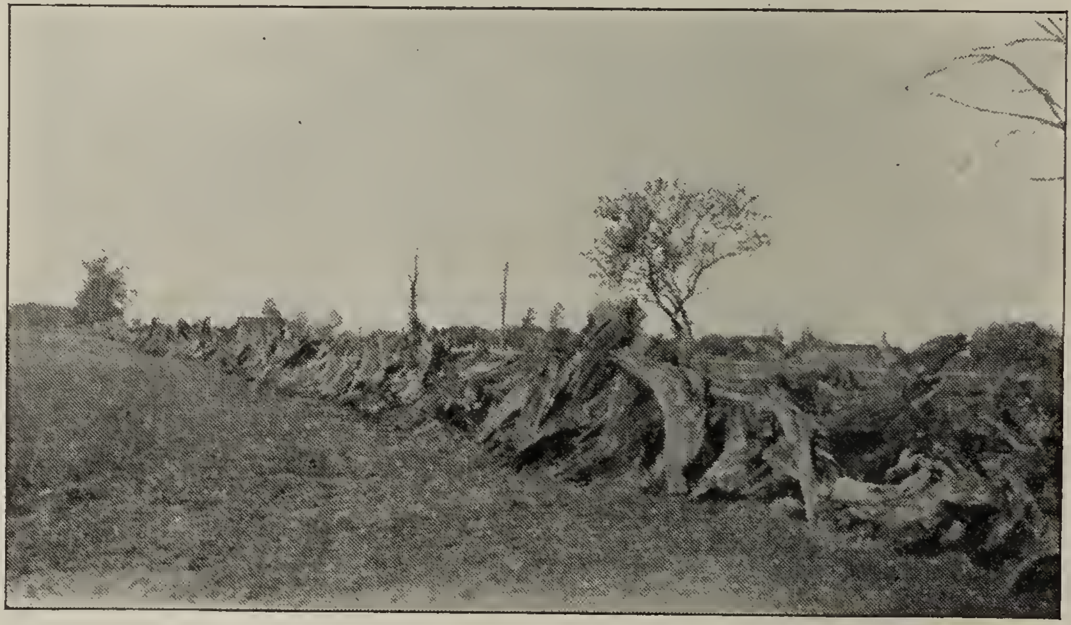

FIG. 9. STUMP FENCE ALONG WHICH EGGS WERE DEPOSITED

The exact number of egg masses deposited by an individual female cannot be stated definitely, but it is generally thought that the usual number is two. Riley (1891) states that "each female in the course of her life usually deposits two of these masses, though at St. Louis I have observed instances in which three and even four were placed by the same female." Other writers since then have reported the usual number to be at least two. From the fact that egg laying continues for six weeks or more, it is reasonable to suppose that at least two egg masses may be deposited by each female.

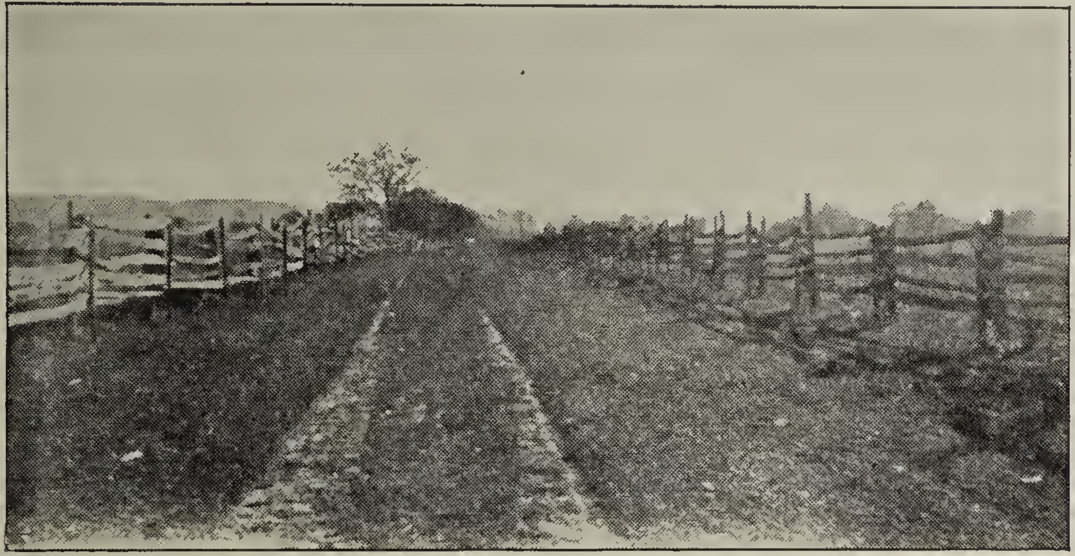

FIG. 10. ROADSIDES ALONG WHICH EGGS WERE DEPOSITED, AND FENCES ON WHICH ADULT GRASSHOPPERS CONGREGATED

NUMBER OF GENERATIONS PER YEAR

The species *M. atlanis* is normally single-brooded, having but one generation a year. It has been reported, however, as having two broods a year in a few instances. Riley (1891) found it to be uniformly double-brooded in Missouri; Garman (1894) found two generations in Kentucky; Thomas (1880) states that this species is double-brooded in the southern part of Illinois. Except for these comparatively isolated cases, *M. atlanis* is essentially single-brooded.

In exceptionally favorable circumstances, however, there may be a slight tendency toward the production of two broods in the same season. In his investigations of the outbreak of this species in New Hampshire in the eighties, Riley (1891) found a tendency toward a second brood. He says: "Some of the earlier laid eggs hatch in autumn, so that there is the same tendency toward a second brood as we find in *spretus*, a tendency which is more marked during a warm, protracted autumn, and which is beneficial to the farmer, inasmuch as all these autumn-hatched individuals invariably perish during the winter." In the writers' investigations at Kirkville in 1915 an instance was found of the tendency toward two broods, to which reference has already been made. In a sandy, slightly sloping, and well-protected field in which egg masses had been laid in considerable numbers, some first-stage and scattering second-stage nymphs of this species were found on August 25. Pressure of other work prevented frequent visits to this place, but on October 25 twelve fifth-stage nymphs were found. Undoubtedly some of the earliest-laid eggs had hatched, as a result of the exceptionally warm weather of the previous season. Instances of this kind are rare, however, and do not furnish ground for believing that the tendency toward double-brood production is more than slight.

NATURAL CONTROL

Were it not for the balance maintained by nature in the animal kingdom, the world would soon be overrun with insect pests of one kind or another. Outbreaks of particular insects are brought about by certain climatic and other conditions which are favorable to a rapid increase in the numbers of these insects and at the same time unfavorable for a corresponding increase in effectiveness of their natural checks. Eventually, however, these natural agencies regain control of the situation, and the normal balance is restored. Among these natural agencies may be mentioned birds and other vertebrates, insects, and diseases.

VERTEBRATE ENEMIES

Without doubt birds deserve first place among the higher animals preying upon grasshoppers. The good work they do in helping to suppress insects in general is often underestimated, but as our knowledge of the habits of birds increases, so does our appreciation of their service as aids in reducing the injury wrought by insects. Possessed of strong powers of flight, the birds are attracted in great numbers to localities where insect food is most abundant. This is especially true where grasshoppers have suddenly broken out in great numbers, and Beal (1900) has written as follows: "There seems to be a pretty general law that all birds, no matter what their food habits may be during the rest of the year, eat grasshoppers in August, just as the human race eats certain delicacies in their respective seasons."

Among the commoner species of birds which either have been observed to eat *M. atlanis* or whose stomachs showed on examination remains of this species, may be mentioned the bobwhite, the English sparrow, and the cardinal. The Bureau of Biological Survey of the United States Department of Agriculture has shown, by examinations of the stomachs of birds, that more than fifty species of the common eastern birds feed to a considerable extent on grasshoppers, including *M. atlanis.*

Turkeys and other domestic fowls have often been heartily recommended as destroyers of grasshoppers. There is no doubt that they will assist very materially in reducing the numbers of grasshoppers, but they are not to be depended on to entirely destroy the pests. Under certain circumstances they may effectually rid a place of grasshoppers. If the fowls are inclosed in a garden or other comparatively small inclosure in sufficient numbers, they will eradicate the pests very thoroughly. But when they are allowed to run loose over a large territory, too much reliance must not be placed on their powers as insect exterminators.

Other vertebrates that prey to a greater or less extent upon grasshoppers are hogs, skunks, toads, snakes, salamanders, and various rodents.

INSECT ENEMIES

PREDACIOUS INSECTS

Although strictly speaking the locust mite is not a true insect, for purposes of discussion it may be considered among the insect enemies of grasshoppers. The locust mite, *Trombidium* sp., is the commonest of all predacious insect enemies, and may be observed at almost any time during the summer, fastened to the body or the wing of its host. It exists by sucking out the juices of its host. Often there are a number of mites on the same insect (Fig. 11); the writers have frequently noticed grasshoppers carrying a dozen or more of them. Unfortunately these mites are not always fatal to their hosts, and grasshoppers infested

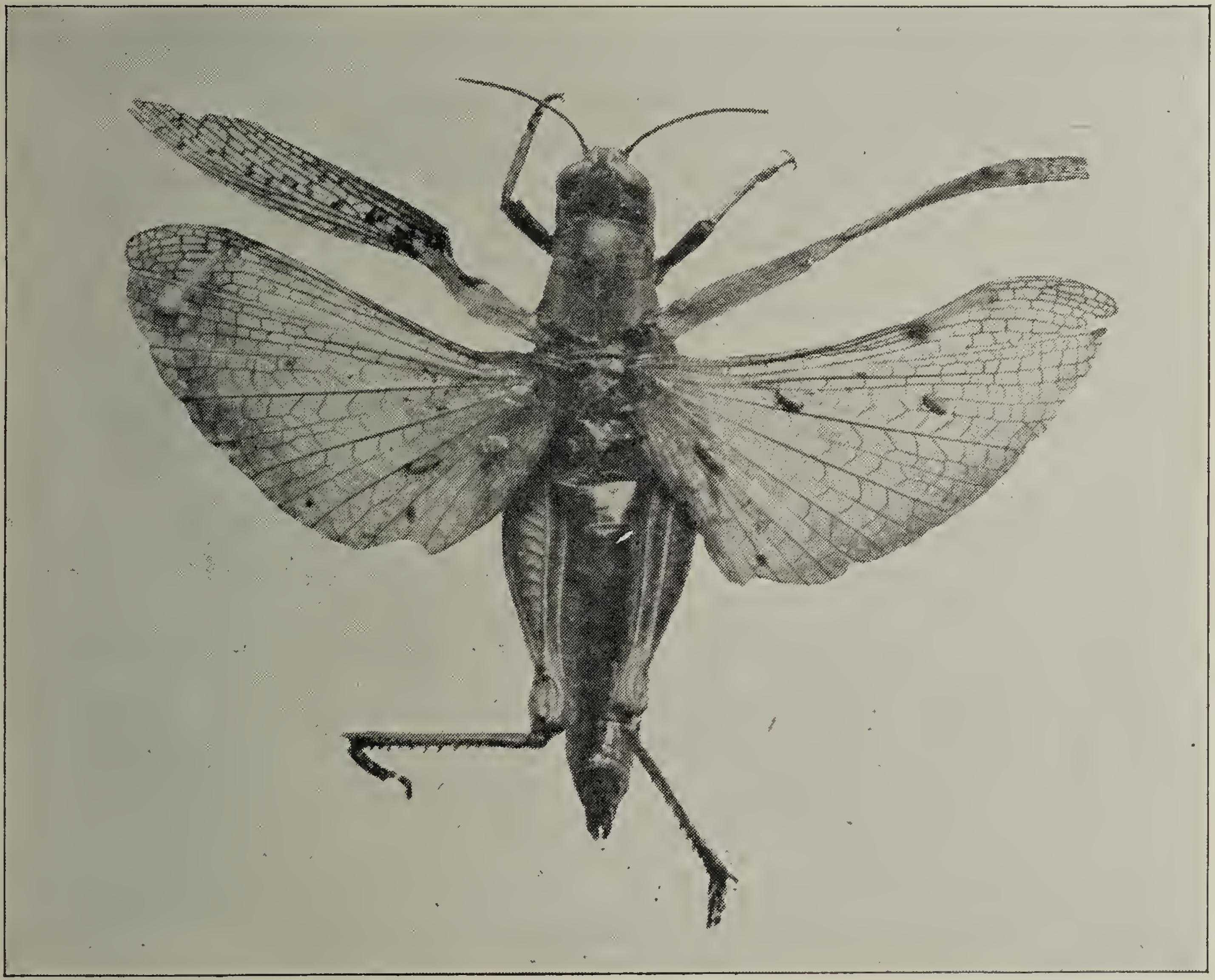

FIG. 11. MITES (TROMBIDIUM SP.) ON WINGS OF GRASSHOPPER

with several do not seem to be seriously hindered by their presence. But without doubt, where there are a large number of the mites attached to and feeding on the same host, the host is generally weakened. It is safe to assume that during the season many of the grasshoppers are destroyed in this way, but it is hardly possible to make a close estimation of the proportion.

The larvæ of bee flies, Bombyliidae, feed on grasshopper eggs. Bee flies are the dark gray, bee-like flies, densely covered with yellow hairs, which are frequently to be seen hovering about grasshoppers in the fields. They lay their eggs on the ground, in the vicinity of the grasshopper egg pods, and the larvæ when hatched feed on the grasshopper eggs.

The larvæ of blister beetles, Meloidae, attack grasshopper egg pods, at times destroying great numbers of them. These blister beetles have a curious life history. The adults, among which may be mentioned the old-fashioned potato beetle, *Epicauta vittata*, often cause great injury to potato and other vegetable plants by feeding on the foliage. The eggs of some species, at least, are laid on the ground and the larvæ feed on grasshopper eggs. The larvæ are very active and hunt around for the egg pods, destroying them when they can find them. They do not always entirely consume the eggs, sometimes merely breaking open the pod, eating part of the eggs within, and then going on to the next pod. In this way, when the egg masses are abundant large numbers will be destroyed by these larvæ, in a measure making up for the damage wrought by their parents. Blister beetles are generally more numerous in a "grasshopper" year, the reason for which is quite apparent.

Many of the ground beetles, Carabidae, feed on grasshopper eggs, in both their larval and their adult stages.

PARASITIC INSECTS

There are a number of insects that are parasitic upon grasshoppers in their later stages, as well as upon the eggs. Among these may be mentioned the tachina flies, Tachinidae, and the flesh flies, Sarcophagidae. The tachina flies are generally grayish in color, and resemble the ordinary house fly but are slightly larger. Both the tachina flies and the flesh flies deposit their eggs on the bodies of their hosts, generally on the neck or under the wings. The maggots hatching from these eggs burrow into the body of their host and feed on the fatty secretions or the vital organs. The grasshoppers are not as a rule killed immediately, but are weakened so much as not to be able to reproduce, and die sooner than those not attacked.

Grasshoppers are sometimes infested with hairworms, or hair snakes, a species of Gordius. These are very long, slender, round worms, which lie curled up within the body of their host, nearly filling it. They weaken the vital organs and eventually cause the death of their host.

DISEASES

One of the commonest natural checks on grasshoppers is a fungous disease, *Empusa grylli*. This disease often causes great mortality among the pests, and the symptoms produced are very characteristic. Grasshoppers affected with the disease instinctively climb upward, crawling up grass stems, weeds, and similar objects. There they die, and their dead bodies remain fastened to these objects in an upright position. After death the bodies become very much softened, and often the ends of the fungus tubes may be seen protruding from them. The spores are scattered from the dead and affected insects, and in this way, when the insects are crowded together in large numbers, the disease spreads rapidly. The most favorable conditions for the rapid development of this disease are continuous warm damp spells, when the locusts are clustered together and when food is scarce.

A bacterial disease was reported as having been the most destructive enemy of *M. atlanis* and related species in Minnesota during the outbreaks there in 1912 (Washburn, 1912).

CONTROL MEASURES

In considering the question of control measures, it must be remembered that we are not dealing with a new or an extraordinary pest, but rather with a common and well-known insect, which has suddenly become a serious menace to crops. In many instances this unusual development of the pest has been made possible, and probably fostered, by slack and more or less antiquated methods of farming.

The general question of control is discussed under the headings *Destruction of the eggs* and *Destruction of young and adult grasshoppers.*

DESTRUCTION OF THE EGGS

Plowing, and disking and harrowing, in order to destroy the eggs, are dwelt upon here because the writers believe that they are the most practicable ways to obtain permanent relief from the outbreaks of grasshoppers in general. As the saying goes, "an ounce of prevention is worth a pound of cure." Other measures, discussed hereafter, can give but temporary relief in most cases.

PLOWING

Fall and early spring plowing is the most important method of permanently controlling grasshoppers in New York State. As has already been pointed out, the eggs are laid as a rule in soil which is fairly compact and which remains undisturbed by the plow — such places, for example, as old pastures and meadows where the grass is thin, along fence rows, lanes, ditch banks, and similar places. Wherever possible such places should be plowed deeply, that is, to a depth of six or more inches, in the fall or the early spring. The reason for such treatment is obvious — to bury the egg masses to such a depth that the young grasshoppers will be unable to work their way to the surface when they hatch. This method is especially applicable to the so-called "grasshopper" sections of the State, the sandy nature of the soil in these places seldom preventing the effectual use of the plow.

DISKING AND HARROWING

Disking and harrowing the ground in the late fall may be done with considerable benefit. These operations break up the top layer of the ground, in which the eggs are laid (they are seldom to be found at a depth exceeding two inches), and expose them to the drying effect of the wind and the sunshine and to the alternate freezing and thawing of winter; in addition many of the eggs thus exposed will be eaten by birds and other animals. It has been demonstrated conclusively in experiments that at least eighty per cent of the eggs so disturbed fail to hatch.

DESTRUCTION OF YOUNG AND ADULT GRASSHOPPERS

POISON BAITS

Without doubt, one of the most successful and least expensive methods of obtaining quick relief from the loss caused by grasshoppers is by the use of poison baits. These may be used against both the young and the full-grown grasshoppers.

The so-called "Kansas bait," as developed by Dean (1914) and Hunter and Claassen (1914) in Kansas, is as satisfactory a bait as has been used. The formula for making this bait is:

Bran	20 pounds
Paris green	1 pound
Oranges (or lemons)	3
Molasses	2 quarts (any cheap sirup may be used)
Water, about	3½ gallons

The bran and the paris green are mixed dry. The molasses and the water are mixed and the fruit is added, chopped fine (an ordinary food chopper is an excellent utensil for this purpose). The bran mixture is then moistened with the liquid. Just enough of the liquid should be used to thoroughly moisten the bran, but not enough to make it sloppy. The bait should be sown broadcast over the infested field, either early in the morning or late in the afternoon, preferably the former so that it will not be dried up by the heat of the sun before the insects have an opportunity to feed on it. It shou'd be sown evenly and thinly over the field, not in lumps. The amount of mixture from the foregoing formula should be enough for from three to five acres. If a larger quantity of the bait is to be made at a time, it will be found advisable to use a large, tight box to mix the materials in, and for the mixer to protect himself from breathing the poisonous dust by tying a moistened sponge or handkerchief over his nose and mouth.

As the bait is likely to be attractive to animals, it is important that livestock of all kinds, including poultry, should be kept from the treated fields for some days, in order to avoid any possible danger of poisoning them. Extra supplies of the poisoned material, as well as the utensils used in preparing the bait, should be kept in a secure place, where livestock and children cannot get at them. If the grasshoppers are especially numerous, or if a rain follows the application of the bait before it has had time to take effect, it will be necessary to renew the treatment in a few days. Most of the insects killed will be found in crevices and hollows, and at the bases of the plants. The writers have often counted as many as thirty or more to the square foot dead from the poison, clustered along the rows of plants.

In cooperation with the State Department of Agriculture the poison bait was applied over a considerable area in the vicinity of Kirkville, New York. The following notes on this work will give a fair idea of the effectiveness of the bait:

On June 7, on the Oot farm at Kirkville, the poison bait was scattered broadcast over a field of young oats in which the plants were about six inches high. The grasshoppers were very numerous, had already eaten bare the first three or four rows, and were working havoc with the rest. On the next day and the day following there were showers, so that the treatment was renewed on the 10th. In both cases the usual formula for the material, as given above, was followed. The bait was applied in the morning. That same afternoon a few dead grasshoppers were to be found, scattered along the rows, and more were rather sluggish and disinclined to move when disturbed. Evidently they were feeling the effects of the poison. The next afternoon, approximately thirty-six hours after the second application, a large proportion of the insects were dead or dying. Along the outer three or four rows the writers counted from eight to twelve dead insects every four inches. The grasshoppers had apparently sought shelter along the rows, and were found huddled together at the bases of the plants. Many sick and dying insects were found also, but no counts of these were made.

On June 17, on the farm of Frank Moth, also at Kirkville, the poison bait was applied to a badly infested oat field already partly eaten by these pests. The standard formula was used, and the material was applied in the morning. The field was examined forty-eight hours later and average counts of the dead insects were made, taking the number on a square foot of ground. The counts showed 47, 25, 28, 33, 37, 19, 27, 15, 29, and 39, giving an average of 30 (or 29.9, to be exact), dead grasshoppers to the square foot. In another instance 18 dead insects were found in a heap in a single horseshoe track. It was also very noticeable that many others were in a dying condition.

On June 22, at the Putnam farm in Peru, Clinton County, a field was examined to which the poison had been applied on the morning of the 20th. Three pounds of paris green had been used to forty pounds of bran, in place of the regular formula, as the insects were very abundant and were doing much damage. Counts of individual areas through the field showed the number of dead grasshoppers to be 37, 19, 49, 26, 12, 33, 19, 18, 34, 41, 38, and 47, with an average of 31, per square foot. In one place near the gateway at the entrance to the field over 300 were counted in a square yard.

Equally satisfactory results were obtained by farmers in the infested sections who applied the bait according to the directions given. Occasionally places were found where the results were not satisfactory, but in almost every one of these that the writers investigated, the reason was obvious. Generally the fault was in applying the bait in the middle of the day, when it would dry out almost as soon as it fell on the hot earth, before the insects had an opportunity to feed on it.

The writers' experience has been that, although the poison does not kill insects immediately, it seems to stop their feeding to a considerable extent as soon as they have eaten it. The poison begins to take effect within a few hours, but does not reach a maximum until from thirty-six to forty-eight hours. As late as four days after the application of the poison bait the writers have found grasshoppers in a dying condition, without doubt as a result of having eaten the material.

Another poison bait recommended is known as the "Criddle mixture." This is composed of paris green 1 pound, salt 2 pounds, horse manure (preferably fresh) about 50 pounds. The paris green, the salt, and the manure are mixed, with enough water added to make the mixture fairly moist but not sloppy. The mixture is then scattered over the infested fields, in a similar manner to that with the Kansas bait described above. Although this material is less agreeable to handle than the Kansas bait, it has the advantage of being less expensive and offers less danger of stock poisoning.

THE HOPPER-DOZER

One of the earliest mechanical devices used for the destruction of grasshoppers is the hopper-dozer (Plate VI, 1). This machine was developed during the days of the notorious Rocky Mountain locust outbreaks in the Western States in the seventies. Hopper-dozers have been in use for years in the grasshopper regions of the West, but do not seem to have been in as much favor in the Eastern States. This machine most certainly has its place in grasshopper control, as the experiments of others, and those carried on under the direction of the writers in 1915, have demonstrated. It seems wise, therefore, to discuss briefly the construction and use of the hopper-dozer.

The hopper-dozer consists essentially of a shallow pan, mounted on runners, with a back shield, and containing water with a film of kerosene or crude oil. The pan may be of plain or galvanized sheet iron, about four inches deep, two feet wide, and of any suitable length, generally eight or more feet. The runners may vary in height but usually should be about two or three inches high. On the back there should be a shield of tin or oilcloth (with the smooth side toward the front) two or three feet high, to keep the insects from jumping or flying over the back. Similar side wings may be added. The pan is partly filled with water, with a generous film of kerosene or crude oil on top, and drawn across the infested fields. Pans up to eight feet long may be drawn by hand; longer ones will need horses or several men. In the longer pans cross partitions should be placed at intervals of two or three feet, to keep the liquid from running to one end on uneven ground. It is of course obvious that the hopper-dozer can be used only on comparatively level ground. On the other hand, the machine is especially useful in places where the use of poison bait is inadvisable or impossible.

It has been stated that in general the insects become winged by the middle of June. It is important, then, that the hopper-dozer should be brought into play as long before that time as possible, for the best results.

Considerable success has attended the use of these machines in the past under eastern conditions. Marlatt (1889) reported their successful use during the grasshopper outbreak of 1889 in New Hampshire. Sixty bushels of insects were collected from an oat field of three and one-half acres. In experiments at Kirkville during the summer of 1915, a small machine about seven and one-half feet long was used. With this, forty gallons of grasshoppers were caught in one field in about three hours. On the first trial about three gallons of insects were caught in the first fifteen minutes (Plate VI, 2). There is no doubt in the minds of the writers that the hopper-dozer could be used to considerable advantage in many cases.

SPRAYING

Where there is some sort of spraying machine available, it may often be used to advantage. The individual farmer must be the judge of the circumstances under which this means of control can best be used. Experimenters have recommended various materials to be used in spraying for grasshoppers, of which the most successful are arsenate of lead, paris green, and sodium arsenite.

Swenk (1913) found that in Nebraska arsenate of lead gave excellent results when used at the rate of 5 pounds of the paste material to 50 gallons of water. The grasshoppers, after having fed on vegetation sprayed with this poison, died in about forty-eight hours. Paris green at the rate of $1\frac{1}{2}$ pounds to 50 gallons of water, with about a pound of fresh lump lime to prevent burning of the foliage, gave equally good results.

Washburn (1912), in Minnesota, used a sodium arsenite spray, such as is in vogue in the grasshopper-infested regions of South Africa, devising a formula which is suited to conditions here. He used commercial sodium arsenite at the rate of 1 pound to 60 gallons of water, with 2 quarts of molasses. It was found that the poison would kill the insects in from twenty-four to forty-eight hours after they had eaten the sprayed grass, but they became paralyzed almost immediately after eating the poison and did not feed any more.

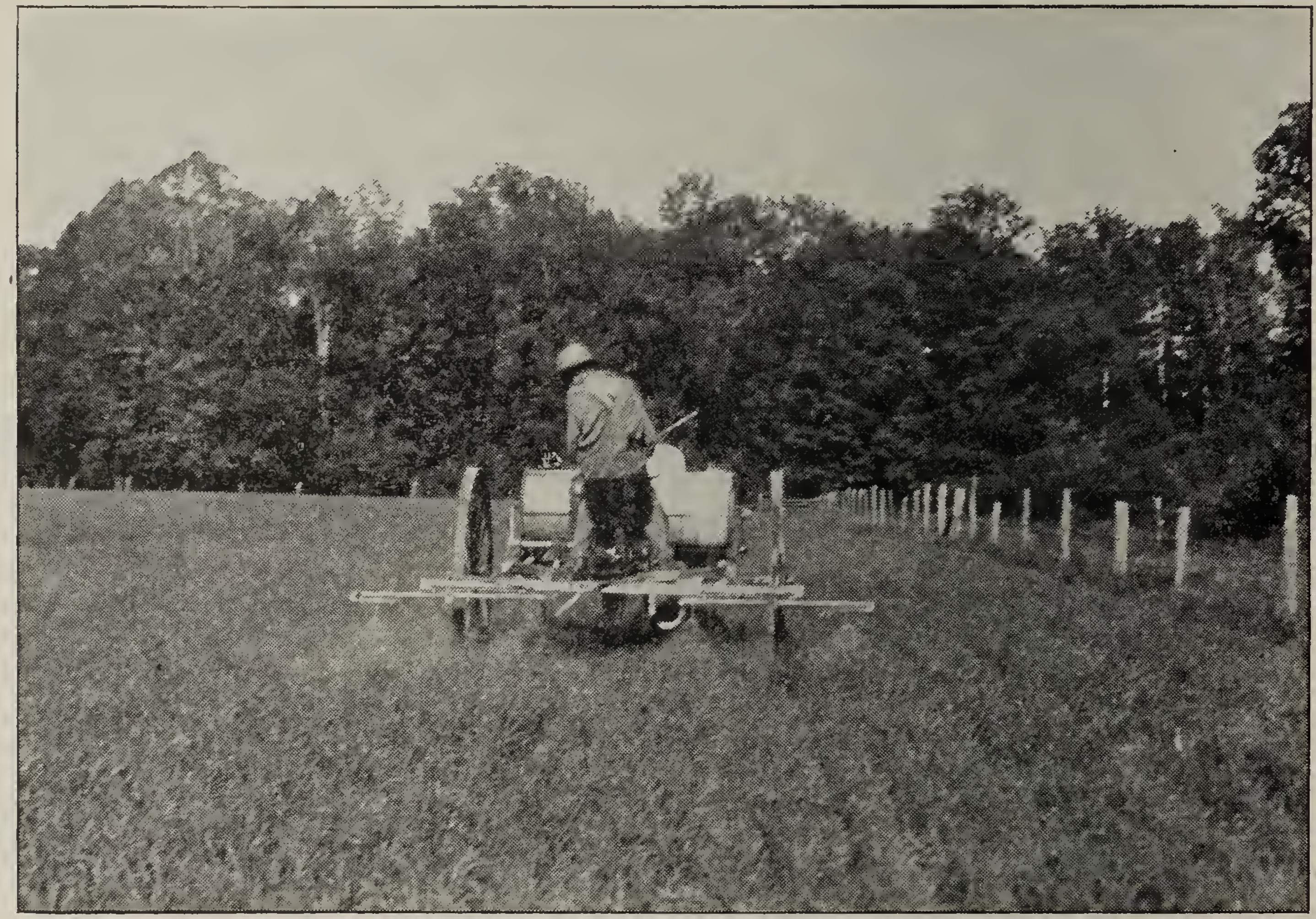

FIG. 12. SPRAYING AN OAT FIELD

In the vicinity of Kirkville the writers had an opportunity to try the effect of poison sprays in checking an invasion of a field of oats by grasshoppers. In cooperation with the owner, the grass in an adjacent meadow in which the insects were abundant was rather thoroughly sprayed with paris green by means of a potato sprayer. The oat field was just beginning to be invaded by the grasshoppers from the meadow, and the first rows of oats were sprayed with the poison solution (Fig. 12). Many of the young grasshoppers were killed, but on the whole the results were disappointing. If the spraying had been followed up and repeated once or twice it would probably have been more effective.

Any spray, in order to be most effective, should be applied early in the season while the grasshoppers are small. Hedgerows, weedy patches, lanes, and similar places, wherever the pests congregate, may be treated in this way, as well as other places where circumstances warrant.

Of course it is highly important that livestock of all kinds be kept away from the areas treated, for some time — at least a week or ten days under ordinary circumstances, or until after heavy rains. If proper care is taken in the handling of poison sprays, as directed above, little danger need be feared.

OTHER METHODS OF CONTROL

Local conditions will often suggest other ways of destroying the pests. Naturally any one method may not be applicable to all situations, and any method that is feasible and seems to apply in the circumstances present should be adopted. Several schemes that the writers have seen used in particular cases with gratifying success may be briefly mentioned.

Plowing under.— It sometimes happens that practically all the grasshoppers on a farm or in a certain locality hatch in a single field or pasture. In such a case it may be feasible to plow under the young grasshoppers. To be effective the plowing must be done as soon as possible after the insects have hatched. In plowing one should always start from the outside edge and work toward the center, throwing the slices of soil ~~inward~~ outward and having them overlap. This will tend to drive toward the center such of the hoppers as escape being buried, and they will generally be unable to cross the plowed ground to adjoining fields in sufficient numbers to cause further apprehension.

Burning.— Occasionally grasshoppers will congregate in a small field of grass or grain for a time. An instance of this kind came under the writers' observation in 1915 at Kirkville, where the owner was very successful in burning over the infested tract and destroying most of the insects. The grass need not necessarily be dry enough to burn completely in a short time. It was found that great numbers of the insects were apparently untouched by the flames but were suffocated by the smoke. Examination of the burned area on the following day showed immense numbers of the insects dead on the ground, many of them burned to a crisp, others with the wings burned off, and still others suffocated as just mentioned. Nowhere adjoining the burned field could the grasshoppers be found in any unusual abundance, even though on one side was a plot of especially fine oats. This method, however, will not be effective in fields where the vegetation is rather scanty, with bare spots of any size, as the writers learned in other instances. The grasshoppers will collect in the bare spots and escape for the most part unharmed. This difficulty might be remedied by covering the bare spots with grass or hay. A day when there is as little wind as possible should be selected for the burning.

Traps.— Trapping the pests is another method that has been employed to advantage in the case of grain or other fields heavily infested. The crop should be cut, leaving several rows or patches on which the insects may feed. These trap rows or patches should be heavily sprayed with arsenate of lead or some other poison, or generously treated with poison bait as already described. In this way a crop may be cut, in order to save it, without necessarily driving the insects to other fields for new food.

Kerosene oil.— The writers have seen kerosene oil spray used very effectively on a farm in Kirkville. A pasture in which grasshoppers were hatching was divided by a narrow lane from several fields of grain. Early in the season the insects gathered in the late afternoon in this lane and on the fences on both sides (Fig. 10, page 23). The owner used to go through the lane just before sundown and spray the ground and the fences with kerosene oil, using a small automatic hand-pressure pump which gave a fine spray. Great numbers of the insects were killed in this way, and, although many escaped by jumping aside as the man passed, by consistent repeated applications the grain crops escaped with but little damage. It was estimated that about 50 gallons of oil was used during the season.

As has been said, the methods mentioned will not always be applicable in every case, but they will perhaps suggest possible schemes that may be utilized to fit individual circumstances. They are offered merely as suggestions, based on the writers' experiences.

GENERAL RECOMMENDATIONS FOR CONTROL

For methods of control in general the writers would recommend the following: fall plowing, and disking and harrowing, to destroy the eggs; use of poison baits, especially the Kansas bait; other methods that may be suggested by local conditions. Above all they would urge thorough, consistent effort, based on a knowledge of the general life history and habits of the insects, with that knowledge intelligently directed and applied to the immediate situation.

NOTES ON RELATED FORMS IN NEW YORK

In addition to *Melanoplus atlanis*, there are several other species of grasshoppers that the writers have often found in close association with that species, and contributing to some extent to the damage caused. As a rule, however, these other forms would not by themselves be abundant enough to become serious pests, although *M. femur-rubrum*, the common red-legged grasshopper, has had a record even worse than that of *M. atlanis*.

The methods of control that have been recommended for the lesser migratory locust are equally applicable to the species now considered. As a general rule, however, there is little need for the adoption of remedial measures for these forms, except possibly in cases of local abundance.

THE RED-LEGGED GRASSHOPPER
(*Melanoplus femur-rubrum*)

Throughout the State as a whole, and indeed throughout the United States in general, *Melanoplus femur-rubrum* (Fig. 13) is much commoner than *M. atlanis*. It is usually spoken of as *red-legs*, referring to its characteristic reddish-colored legs. The lesser migratory locust and this form are difficult to distinguish from each other, even by specialists, so close is the resemblance between them in form and color. This is especially true of the females.

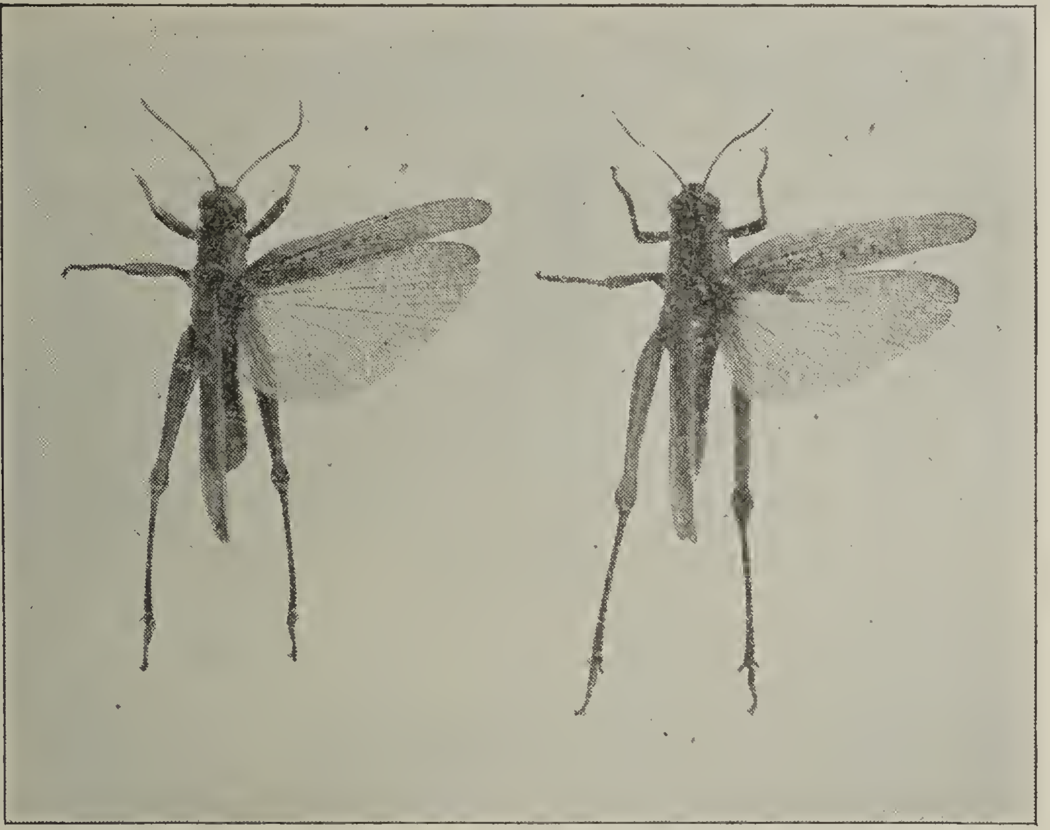

FIG. 13. THE RED-LEGGED LOCUST (MELANOPLUS FEMUR-RUBRUM), MALE AND FEMALE. NATURAL SIZE

The life history of the red-legged grasshopper does not differ in any material respect from that of the lesser migratory locust. It is said to be a frequenter of low ground, but the writers found it common on high ground both at Ithaca and at Kirkville in 1915. It is often found along the margins of cultivated fields and along the shady edges of woods, where the vegetation is tender and succulent. It is seldom to be found in numbers on very dry hillsides and meadows, differing in this respect from *M. atlanis*, which prefers drier, more arid locations.

The following brief statement of some of the more obvious differences in form between the two species, as given by Washburn (1912) will aid in separating them:

Lesser migratory locust.— General color tan or yellowish brown; larger part of "hind leg" has two distinct bars on the outer face; tip of abdomen in males, always with a distinct notch.

Red-legged grasshopper.— General color reddish brown, without distinct bars on hind legs; usually smaller and shorter winged than the above.

The writers have collected this species from Peru, Kirkville, Gloversville, and Ithaca. At Peru the insects were occasionally found associated with *M. atlanis*, but more commonly along the edges of fields and woods. At Kirkville and Gloversville they were found in similar places. On one farm located near the edge of the grasshopper-infested section in Kirkville, the insects were fairly abundant in a field of clover but did not appear to be doing any appreciable harm. At Gloversville they were more abundant in the city than in the surrounding territory. At Ithaca this species is much commoner than *M. atlanis*. The insects are found along the edges of cultivated fields and woodlots and in clover fields, but not in numbers sufficient to cause damage. On October 31, 1915, the writers found a number of these grasshoppers on the grassy slope outside the insectary, among them several pairs mating; and on November 7, also on the same slope, they found one pair mating. From these observations it would appear that this species continues to be active later in the fall than does *M. atlanis*.

H. H. Knight, a graduate student at Cornell, has collected *M. femurrubrum* at Batavia and at McLean. In 1912 he found the insects to be abundant on high ground, but not on low ground.

THE TWO-STRIPED GRASSHOPPER

(*Melanoplus bivittatus*)

The two-striped grasshopper, *Melanoplus bivittatus* (Fig. 14) — known also as the yellow-striped grasshopper — may often be found associated with *M. atlanis*, and in recent years this species has been the most serious grasshopper pest in Minnesota, according to Washburn (1912). In New York State it is occasionally found in considerable numbers in localized places, to the exclusion of other species. It has not, however, been a serious pest in New York State as yet.

M. bivittatus is one of the largest species, the female being an inch and a half or so long, with a rather heavy, chunky body. The insect is usually of a dull olive brown or drab color, with a conspicuous yellow stripe along each side of the back running from the head nearly to the tips of the wings. These stripes are very noticeable, as a rule, and distinguish this species when at rest from other forms.

Ordinarily the insects of this species frequent bottom lands, edges of cultivated fields, margins of woodlands, and shaded mountain slopes, but in times of excessive abundance they will spread out over cultivated fields, causing much injury to crops. *M. bivittatus* reaches maturity somewhat later in the season than does *M. atlanis*, and disappears earlier in the fall. The egg masses are larger, containing from 39 to 82 eggs according to Somes (1914).

The writers have collected this species at Kirkville, Batavia, and Ithaca. At Kirkville the insects were found occasionally associated with *M. atlanis*, but more generally along the edges of fields and open pastures. In one field at Kirkville, where rye had been grown, the insects were found in some abundance along a sandy ridge running through the field to the edge of a woods. They far outnumbered other species, but as the rye had been removed it was not possible to determine whether they had caused any appreciable damage. H. H. Knight has collected the species at Batavia, McLean, and Ithaca. At Ithaca he found the insects in abundance on the Renwick Flats.

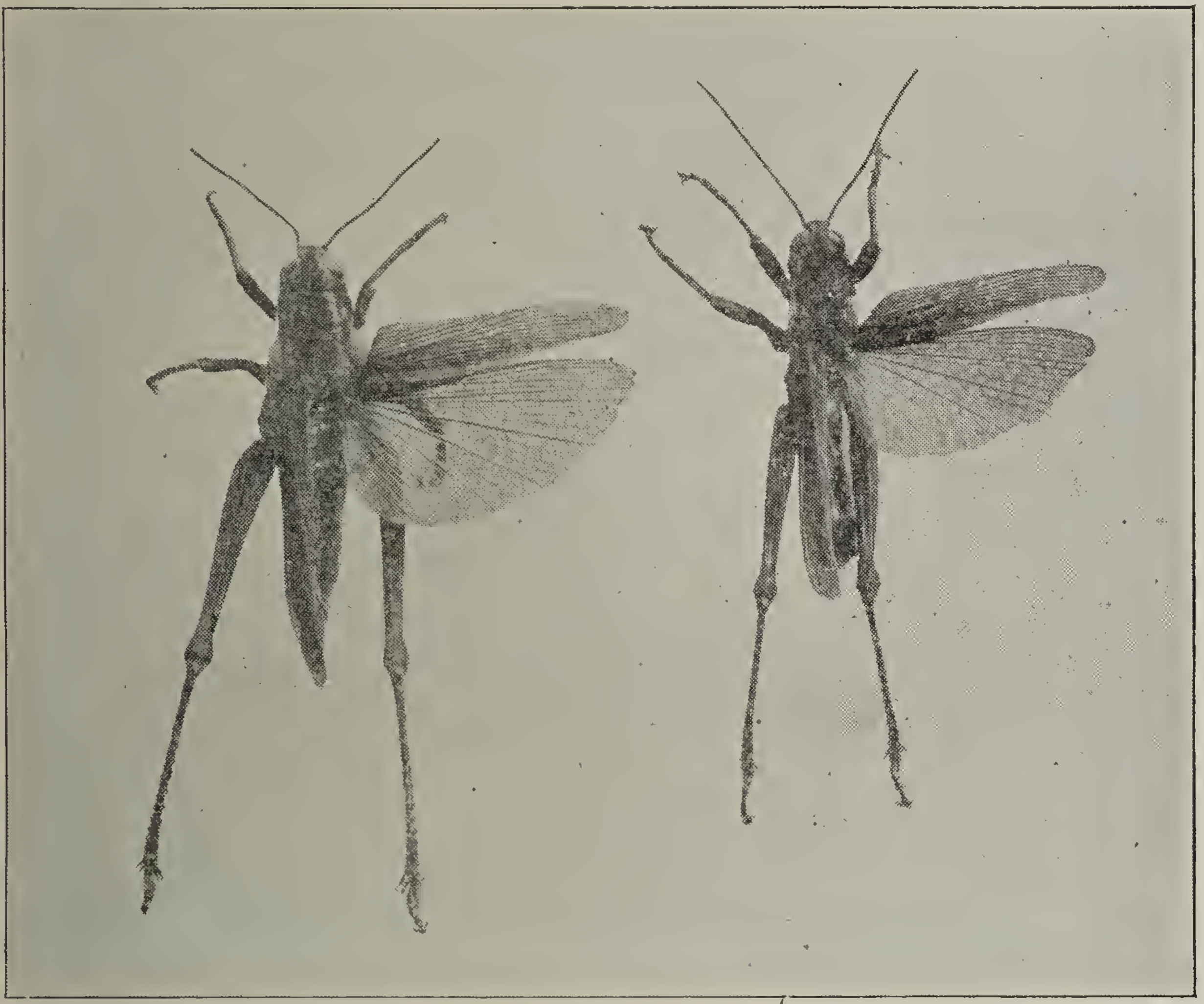

FIG. 14. THE TWO-STRIPED GRASSHOPPER (MELANOPLUS BIVITTATUS)

THE CLEAR-WINGED LOCUST
(*Camnula pellucida*)

The clear-winged locust, *Camnula pellucida* (Fig. 15) — known also as the yellow-winged, or pellucid, locust — is fairly common, and in some States, notably Minnesota, Idaho, and Utah, it has at times been a most serious pest. In New York State it is generally associated with *M. atlanis*. It generally frequents high, dry soil, and is swift in flight. The general color is light brown; the outer wings are brownish with dark-colored spots, and the hind wings are transparent. This species is slightly smaller than *M. atlanis*. The two species mature at about the same time, and in general their life histories correspond.

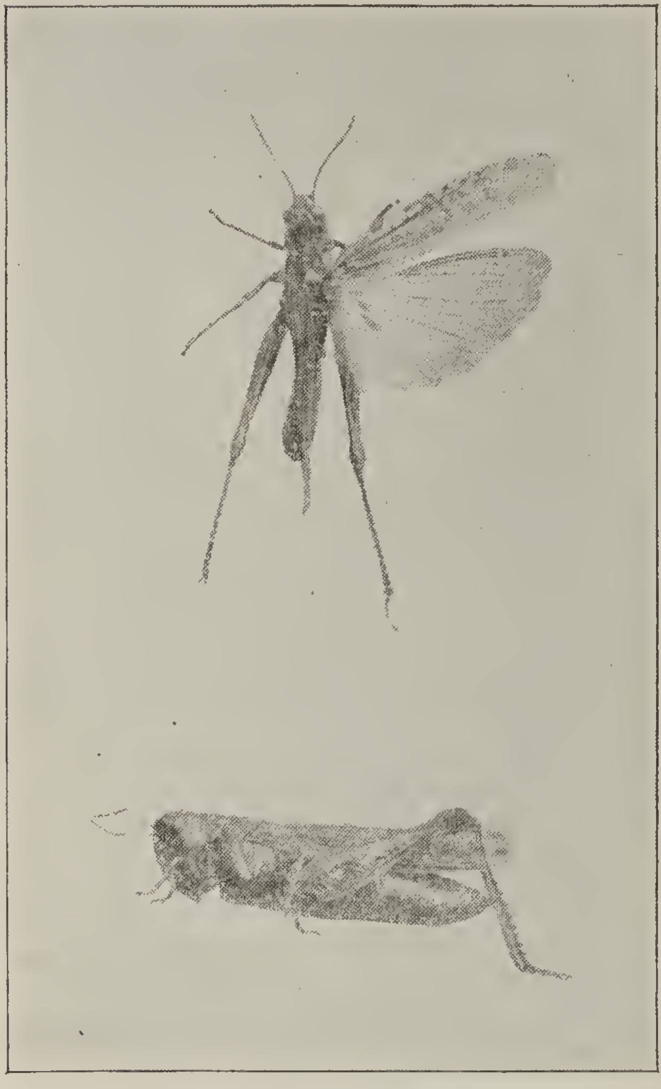

Fig. 15. THE CLEAR-WINGED LOCUST (CAMNULA PELLUCIDA)

The writers have collected adults of this species at Peru in June, and at Ithaca. At Ithaca they may be found occasionally during the summer. Felt (1915) found them in large numbers at Wellsville, associated with *M. atlanis*, on August 3, 1914.

THE CAROLINA LOCUST
(*Dissosteira carolina*)

Because of its large size and striking coloration, the Carolina locust, *Dissosteira carolina* (Fig. 16), is the one oftenest noticed by the casual observer and the one supposed to be the commonest kind. Its peculiar habits would seem to lend color to this belief. It frequents open places, such as roads, pathways, and banks, rather than more secluded spots; when disturbed it flies to open spaces, depending for concealment on the close resemblance between its coloration and its immediate environment. As a matter of fact it is one of the commonest forms, but it is not abundant and should not be classed with the more injurious species.

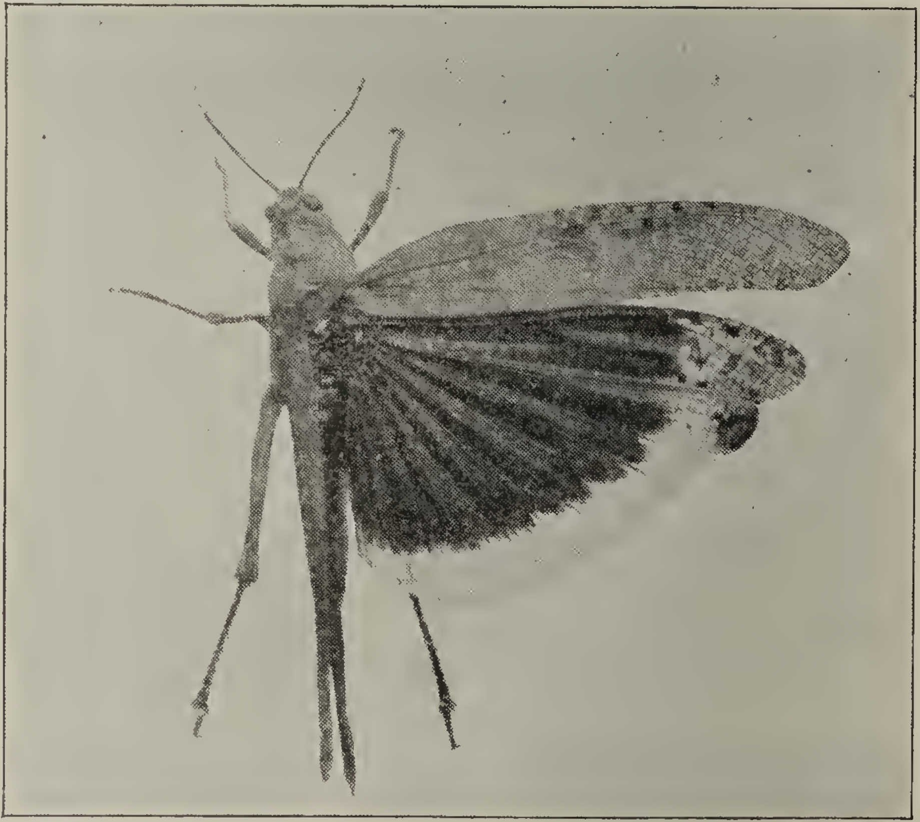

Fig. 16. THE CAROLINA LOCUST (DISSOSTEIRA CAROLINA)

The Carolina locust is very erratic in its flight, especially the male. The male rises to a height of several feet and remains there almost stationary, vibrating its wings at a tremendous rate and producing a characteristic whirring sound. This habit has been thought to be associated with the mating instinct. The insects of this species are rather large, often measuring when at rest an inch and a half or more from the head to the tips of the wings. The usual color is pale yellowish brown with dusky spots, the hind wings with broad yellow hind margins. The color of the outer wings is subject to great variation, being of a shade that will best harmonize with the immediate surroundings; thus all variations from light yellowish to reddish black may be found. This species likes warm, sandy spots, and the close correspondence of its coloration to that of the immediate neighborhood affords it excellent concealment while resting on the ground.

This species is somewhat later in its development than *M. atlanis*, its eggs being deposited in the late fall and hatching late in May or June, as a rule.

The writers have collected *D. carolina* at Kirkville and at Ithaca. At Ithaca the species is especially common along sandy lanes, railroad embankments, and in bare spots or places sparsely covered with vegetation. H. H. Knight has found it to be common at Batavia and has collected it also at Olcott.

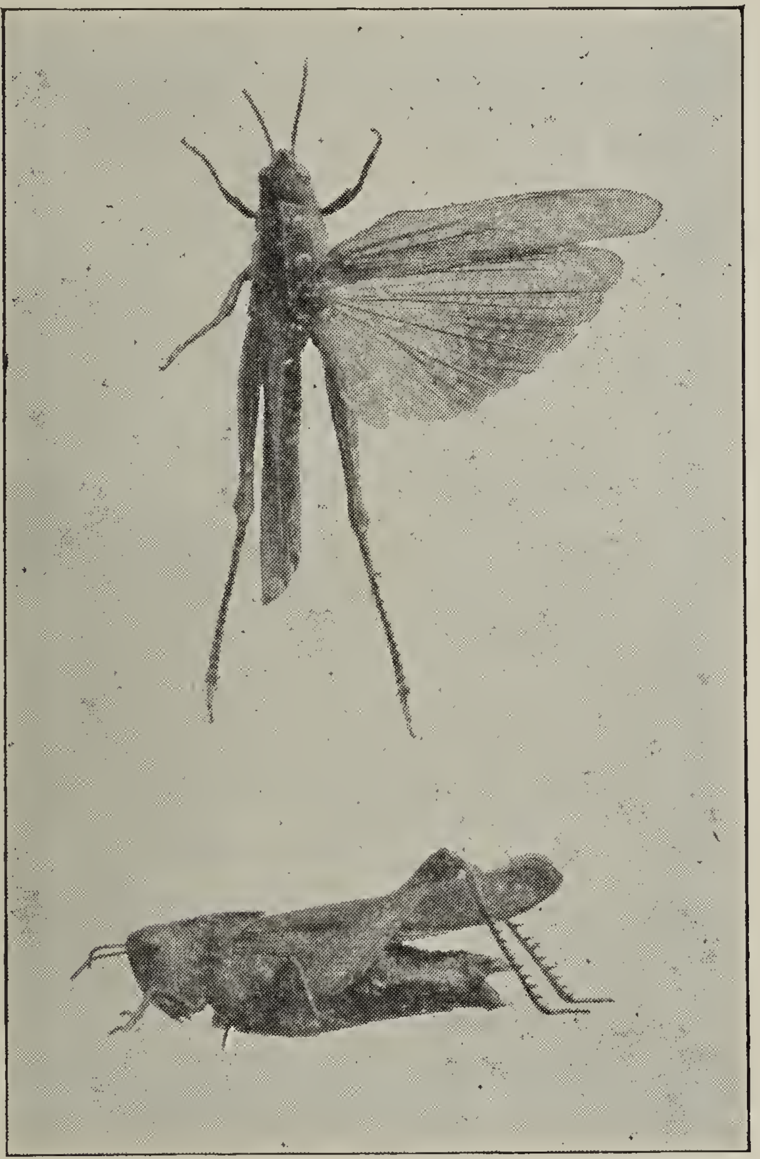

FIG. 17. THE GREEN-STRIPED GRASSHOPPER (CHORTOPHAGA VIRIDIFASCIATA)

THE GREEN-STRIPED GRASSHOPPER

(*Chortophaga viridifasciata*)

The green-striped grasshopper, *Chortophaga viridifasciata* (Fig. 17), is a comparatively common species, and because of its somewhat unusual life history it often causes considerable alarm. The insects hibernate as partly grown nymphs, hidden away in rubbish, among old grass stems, and in similar sheltered places. A warm, sunny spell in winter is quite likely to bring them forth from their sheltered hiding places, and it is not at all uncommon to see them hopping around on sunny days in January and February, apparently quite unmindful of the fact that it is still winter. Sometimes they appear in considerable numbers, causing much apprehension in the minds of persons seeing them. These midwinter appearances are not, however, to be taken as indications of a bad grasshopper year to follow, as this species has never been known to be abundant enough in New York or neighboring States to be of economic importance.

The full-grown grasshoppers are typically green in color, although dimorphic brown and brownish green individuals are not at all uncommon. The majority of the males are brown, while the females tend toward greenish shades. This species is larger than *M. atlanis*, the insects being an inch and a quarter or more in length, with a comparatively heavy body.

Briefly the life history is as follows: As already stated, the nymphs hibernate during the winter, appearing at intervals on warm, sunny days. This habit may be illustrated by the following notes from the writers' records:

February 21, 1915. Nymphs numerous in grass along edges of fields at East Ithaca.
February 23, 1915. Nymphs numerous in grass on experimental plats, Ithaca.
March 15, 1915. Nymphs found along sides of bank near Forestry Building, Ithaca.

H. H. Knight observed the nymphs in some numbers at Ithaca on March 19 and 29, 1913. By the latter part of May they are fairly common and have reached the last nymphal stage, as shown by the following notes:

April 4, 1913. Nymphs in last nymphal stage common at Ithaca (Knight).
April 21, 1912. Nymphs in last nymphal stage common at Ithaca around insectary (Knight).
April 26, 1913. Nymphs in last nymphal stage common at McLean (Knight).

This is the earliest species, and the chirping of the insects begins the general chorus of the season of grasshoppers, locusts, and crickets. The adults emerge during May, as indicated by the following notes:

May 8, 1915. Adults found at Ithaca.
May 11, 1915. Adults and last-stage nymphs found at Broadalbin.
May 15, 1915. Adults collected at Taughannock. (Specimens in C. U. collection, collector unknown.)
May 17, 1913. Adults common at Ithaca (Knight).
June 15, 1913. Adults found at Ithaca (Knight).
June 22, 1915. Adults found at Batavia (Knight).

Shortly after emergence the females deposit their eggs in small holes in the ground, forming masses as in the case of *M. atlanis*; those of the latter, however, are smaller. The eggs hatch later in the summer and the nymphs hibernate during the winter. The writers have never collected adults of this species during the summer and therefore believe that there is only one brood a year, although Lintner (1885, 1893) states that the species is double-brooded. Nymphs become common again in the fall, and the writers found them in some numbers around the insectary as late as November 31, in the fall of 1915. In other States there is but one brood.

SUMMARY

The lesser migratory locust, *Melanoplus atlanis*, is undoubtedly a native species and is widely distributed in the United States and Canada. In many States it has at times been a most destructive pest.

In New York this species caused considerable injury to crops in the western counties in 1893 and 1894. During the last three years, as a result of the favorable seasons of 1912 and 1913, the sandy sections of Clinton, Warren, Saratoga, Fulton, and, to a less extent, other counties, were subjected to an exceedingly severe outbreak of this pest.

The sections in which the grasshoppers appeared in abnormal numbers were remarkably similar in soil, vegetation, kinds of crops grown, and general type of farming, and differed very markedly from closely surrounding regions.

Rye, oats, and corn suffered the most, probably because they are the chief crops of the infested localities. Practically all other crops were injured to a greater or less extent.

The eggs of the grasshoppers hatch in the spring, and the hatching period may be prolonged if conditions are not favorable.

The young nymphs subsist for a time on the surrounding vegetation, so that their presence may not always be noted until they have reached considerable size. During their lives the nymphs undergo five molts, the wings becoming fully developed after the last molt. The length of the time between the different molts varies, and is dependent on such factors as temperature, moisture, and food supply.

The transformation from nymph to adult occurs as a rule during June, and most of the insects have developed wings by early July.

The grasshoppers feed in the middle of the day; at night and on cold, damp days they seek shelter. There is no definite migration in swarms, but they may drift from place to place in search of food as the available supply in any one place becomes exhausted.

Mating commences early in July and the mating period extends through the summer. Egg laying begins about the middle of July, and thereafter eggs may be deposited at any time until cool weather sets in. The eggs are deposited in a pocket in the ground made by the female, and form a small pod-like mass or capsule. Rather sandy soil which is fairly compact and rather sparsely covered with vegetation is chosen for egg laying; such conditions are usually met with in closely grazed pastures, in meadows of long standing where the grass has become thin, and along the edges of lanes, paths, and shallow ditches or furrows running through such places. Usually the egg masses are not found at a greater depth than from one-half to one and one-half inches below the surface of the ground. As many as seven egg masses to the square foot have been found in the most heavily infested localities, but the average number is considerably less.

This species normally has but one generation a year in New York State.

Birds, predacious and parasitic insects, and diseases are important factors in the natural control of grasshoppers. Turkeys and other domestic fowls, and various mammals, assist in reducing the numbers of the pests.

Fall and spring plowing of the breeding places of the insects is the most practicable method of permanently controlling grasshoppers in this State. The breeding places should be plowed to a depth of six or more inches, so as to break up and bury the egg masses. Disking and harrowing is of considerable benefit in breaking up the egg pods and exposing them to the effects of winter weather and to the attacks of birds and animals.

One of the most successful and least expensive methods of obtaining quick relief from the ravages of the pests is the use of the so-called "Kansas bait," a kind of poisoned bait. This is composed of bran 20 pounds, paris green 1 pound, 3 oranges or lemons chopped fine, molasses (of a cheap grade) 2 quarts, and enough water to moisten the bran and other ingredients (about 3½ gallons). The mixture should be scattered thinly over the infested areas early in the morning. Care should be taken to keep all livestock from treated areas. Very gratifying results have been obtained from the application of this bait.

The hopper-dozer may be employed to advantage under some conditions, and wherever it can be used it offers a quick means of destroying large numbers of insects in a short time.

Spraying may be resorted to at times, and other methods may be found practicable in individual cases. Any of these methods should be made use of whenever feasible.

Besides the lesser migratory locust, other species have been found in less numbers. These are the red-legged grasshopper, the two-striped grasshopper, the clear-winged locust, the Carolina locust, and the green-striped grasshopper.

ACKNOWLEDGMENTS

The writers desire to express their appreciation of the opportunities offered for carrying out the work at Kirkville, New York, by C. N. Dewey, of that town. Mr. Dewey not only placed at the writers' disposal necessary equipment, but also himself assisted very materially during the progress of the investigation.

The writers desire to acknowledge their obligations also to L. L. Woodford, of the State Department of Agriculture, who collaborated in the control work.

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AGRICULTURAL EXPERIMENT STATION

BLACK ROT, LEAF SPOT, AND CANKER OF POMACEOUS FRUITS

L. R. HESLER

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BLACK ROT, LEAF SPOT, AND CANKER OF POMACEOUS FRUITS[1]

L. R. Hesler

HOST CONSIDERATIONS

PLANTS CONCERNED

The black rot, leaf spot, and canker of pomaceous fruits is primarily a disease of the apple, *Pyrus Malus* L. It affects other trees also, however, especially the pear (*Pyrus communis* L.), the quince (*Cydonia vulgaris* Pers.), and the crab (*Pyrus coronaria* L.), showing on these hosts symptoms similar to those on the apple. In addition the pathogene infests the dead parts of a great variety of other trees and shrubs, but in such cases there is usually no evidence that it has been the causal factor in the death of the tissues. In the State of New York, at least, this disease is of economic importance only on apple trees.

VARIETAL SUSCEPTIBILITY

OF FRUIT TO BLACK ROT

The summer varieties of apples are affected by black rot at the time of ripening, while winter varieties commonly suffer in storage. In Connecticut black rot is a most troublesome storage rot (Clinton, 1915:5).[2]

OF FOLIAGE TO LEAF SPOT

Brooks and DeMeritt (1912:183), in New Hampshire, note striking differences in the varietal resistance of apple seedlings to leaf spot. In Virginia, Ben Davis and Black Twig are more severely attacked than are other varieties (Reed, Cooley, and Rogers, 1912:5). Salmon (1907), writing from England, states that among the varieties most affected there are Peasgood, Nonsuch, Cox's Orange, and others. The writer has noted that Chenango, Baldwin, Rhode Island, and Twenty Ounce show spotted foliage more commonly in New York than do other varieties.

OF LIMBS TO CANKER

Varieties of apples exhibit a marked difference in susceptibility to the disease, and this variation is not the same with respect to the different parts affected. In western New York Twenty Ounce is the variety most severely affected by the canker. This variety is rarely found unaffected by canker, even in orchards that are managed according to improved methods. Neglected trees of the Twenty Ounce variety are often killed.

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[1] Also presented to the Faculty of the Graduate School of Cornell University, May, 1914, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

[2] Dates in parenthesis refer to bibliography, page 126.

Paddock (1899 b: 181) says that certain growers in New York State have noted that Twenty Ounce is most likely to be attacked. He lists other varieties in order of their susceptibility, as follows: Baldwin, Wagener, Rhode Island, Tompkins King. Regarding the Esopus, Paddock (1899 b: 180) says that this variety has apparently run out because of this disease. In Ontario, Ben Davis, Northern Spy, and other varieties are severely injured by the disease (McCready, 1910).

THE DISEASE

NAMES

The disease on the fruit is called *black rot*, *ring rot*, *blossom-end rot*, and *brown rot*. The first name is descriptive and definite, and seems desirable.

Lesions on the foliage are termed *leaf spot*, *brown spot*, and *frog-eye*.

The names *apple canker*, *black rot canker*, and *New York apple tree canker*, are most commonly applied to the disease when it occurs on the bark. The term *apple canker* needs some qualification, since many kinds of cankers occur on the apple. It was under such an exigency that Paddock (1899 b: 180, footnote) first used the name *New York apple tree canker*. The writer prefers to use this name regardless of its length, not alone because of priority, but also because of general usage.

HISTORY

THE BLACK ROT OF THE FRUIT

The disease on the fruit was observed by Peck (1879: 20) in Schoharie County, New York, and he quotes the remark of stagecoach passengers that they "never before knew of apples rotting on the tree." Arthur (1885) records black rot of quince fruit at Geneva, New York, and notes the importance and infectious nature of the disease. Scribner (1890) notes the disease in New Jersey and describes the symptoms and causal nature. The same year Baccarini (1890), in Italy, observed the rotting of otherwise sound apples, pears, and peaches, the decay occurring in a storeroom of fruit gathered when ripe; this was a new appearance of the disease in that country. Two years later Halsted (1892) discussed the black rot of quince in New Jersey. Sturgis (1893, a and b) notes the disease on quinces in Connecticut in August, 1892, and later (1894) confirms the work of Halsted. Kinney (1895 c) figures and describes the disease in Rhode Island. In the same year it became an object of control measures in Kentucky (Garman, 1895). Black rot of apple is reported by Burrill and Blair (1901) in Illinois; they give a careful description of the disease and distinguish it from other apple rots. The following year Clinton (1902), writing from the same station, remarks that the disease on apples had attracted attention for several years, and that it was known to have occurred in Illinois at least as early as 1879. The disease as a storage rot was studied by Lamson (1902) in New Hampshire the same year. Faurot (1912) describes the disease in Missouri.

W. A. Orton (1904, 1905, 1906, 1907) publishes records of the black rot of pome fruits, the reports having come to him chiefly from the Middle West. In 1905 the black rot of quince and pear was especially injurious in Ohio. Evans (1910) called the attention of the apple growers of South Africa to the disease, which had just been found on apples at Grahamstown and also in a consignment of apples from Sidney, Australia. He urged the importance of excluding the disease from the Transvaal. Recent studies on black rot have been reported by Wolf (1913) in Alabama.

THE LEAF SPOT

The earliest record which the writer has found concerning the leaf spot is that by Alwood (1892), who reports brown spot of apple foliage in Virginia. He had noticed it for several years but states that it was not serious until 1891, when an outbreak occurred over the State. Kinney (1895 b) describes the disease in Rhode Island on apple and pear leaves, and says that it was very common in that State in 1895. Stewart (1896) reports having found the disease on Long Island in May, 1895; he notes that it had been observed in 1894 at Westbury, Long Island, by Professor Beach. Lamson (1899) lists the disease from New Hampshire and reports it as having done serious damage in some cases. Corbett (1900) reports "brown spot," or "frog-eye," as common throughout the southern and eastern counties of West Virginia, and as being more injurious than either blight or scab. Stewart and Eustace (1902) studied the cause and control of leaf spot in the eastern United States. The same year Clinton (1902) notes the severity of the disease in Illinois, and later (Clinton, 1904) he reports its common occurrence in Connecticut. Stone and Smith (1903) record it as one of the most noticeable diseases of the season of 1902 in Massachusetts. Scott and Quaintance (1907) report the spotting of apple foliage in the Ozark region, and in the following year there appeared a more extensive work on the leaf spot problem by Scott and Rorer (1908). Work on the leaf spot was begun in New Hampshire in 1908 by I. M. Lewis (1908); this investigation was carried further by Brooks and DeMeritt (1912), who report it in full. Recent work on the leaf spot form of this disease has been published in Virginia by Crabill (1915).

THE CANKER FORM

According to Paddock (1899 b: 180), orchardists have been familiar with this canker disease for years. Attention was first called to the injury by Waite (1898 a), in a paper read at the meeting of the Western New York Horticultural Society in 1898. In the spring of 1898, Paddock (1898, a and b, and 1899 a) began investigations which extended through two seasons. He records having noticed the disease as early as 1891, and says that it became important about 1895. In 1897, according to Paddock (1899 b:192), considerable "twig blight" was found at Odessa, New York.

Mangin (1901) reports the disease in France on branches of apples, describing its symptoms in order, as he says, to put horticulturists on guard against invasion of the country by the pathogene. The same year Chester (1901, a and b), in Delaware, observed what he believed to be the same disease on apples and pears. His attention had been called to the canker on the latter host in the spring of 1900, near Smyrna. His illustrations suggest the possibility that the disease was the superficial bark canker of Edgerton (1908). A few years later Lochhead (1905) described the disease in Canada. Clinton (1907), writing from Connecticut, states that his attention was called to a peculiar disease of apple limbs in the spring of 1906.

Another record of the disease which has appeared from France is that by Griffon and Maublanc (1910). They note very serious injury to pears in that country, and assert that at the national school of agriculture the disease was first known in 1908. A study of the disease was taken up in Canada by Bethune (1909). He reports a great amount of damage from cankers in the region east of Toronto. The following year a synopsis of the investigations in the province of Ontario was published by McCready (1910). A point of interest noted in this paper is that the great freeze of 1903–1904 in Prince Edward County marked the beginning of the canker epiphytotic there. The disease has received further attention in France by Arnaud (1912), who lists it as occurring on a number of different plants.

GEOGRAPHICAL OCCURRENCE

The disease has a very general distribution throughout the temperate regions of the globe. Heretofore it has been regarded as a disease peculiar to eastern and middle western America, but it is now apparent that its limit is no longer to be so regarded. It has been found in Canada, particularly in Ontario (Bethune, 1909), Quebec (Lochhead, 1905 and 1909), and Nova Scotia (Plant Pathology Herb., Cornell University Exsicc. no. 2657, and Güssow, letter to the writer). It occurs in Europe from Italy to England, according to the observations of Shear (1913:81–82). From England Berkeley (1836) reports it on apple fruit, while Salmon (1907) found it on apple foliage. It is unknown in Norway (Schöyen, letter to the writer), while both Ravn and Lind (letters) state that it is not present in Denmark. From Russia the disease has been reported by Potebnia (1907 and 1910). Jaczewsky (letter to the writer) states that the black rot and canker forms occur in the provinces of Kharkof and Tchernigof, and in the Transcaucasian and Turkestan regions. Potebnia (letter) has collected all the forms in Kursk, near the city of Fatej, and states it as his opinion that the disease occurs generally throughout Russia. Bubák (1909) reports it from Austria-Hungary. It probably occurs in Switzerland, Germany, and Holland, according to the general statement of Shear (1913:82). Kirchner (1906:440) lists it from Germany. It may not be prevalent there, however, for Hollrung (letter) says the disease is not well known in Sachsen. Its occurrence in France is reported by Arnaud (1912) and others. The black rot form has been collected in the vicinity of Brussels, Belgium, by Bommer and Rousseau (1885). Some years ago it was introduced into Cape Colony from New South Wales (Evans, 1910:62, footnote).

So far as the writer has been able to ascertain, the disease is widely distributed in America. It does not occur, however, so far as indicated by results from a circular letter sent to the plant pathologists of the state agricultural experiment stations, in the following States: Arizona, Colorado, Florida, Idaho, Louisiana, Montana, Nevada, North Dakota, South Dakota, Tennessee, Utah, Washington, Wyoming, and possibly Oregon. The canker form is commonest in the East, especially in New York, while fruit rot seems to occur more frequently in the New England and Middle Atlantic sections, although Wilson (1913) reports its occurrence throughout North America east of the Rocky Mountains. In the Middle Western States, particularly Ohio and Indiana, the pear and quince, as well as the apple, appear to have suffered considerably. Quaintance and Scott (1912) state that the leaf spot occurs in all sections east of the Rocky Mountains where the apple is grown. In another publication Scott (1912) asserts that it is found in all humid sections of America. According to Reed, Cooley, and Rogers (1912:3–4), "frog-eye" is widespread in Virginia. Other States in which the disease occurs are Arkansas, Connecticut, Illinois, Maryland, Massachusetts, Missouri, Nebraska, New Hampshire, New York (particularly Long Island), Rhode Island, and West Virginia (Scott and Rorer, 1908:48–49).

Probably no apple disease except apple scab is commoner in New York State than the one here considered. Throughout western New York the canker form is very prevalent. From replies to a circular letter sent to fruit growers in various parts of the State, it appears that this disease is more or less common and serious in all sections, except possibly in the central eastern part. The fruit and foliage rarely suffer appreciably in the State, although black rot and leaf spot are not infrequently found.

ECONOMIC IMPORTANCE

GENERAL CONSIDERATIONS

The nature of the losses caused by this disease makes very difficult the possibility of an estimate concerning them. So far as the writer has found, no reliable data are at hand in regard to this point. The combined injuries produced by the canker, the black rot, and the leaf spot are doubtless greater than is commonly supposed. It is undoubtedly true that the New York apple tree canker is often confused with other cankers by some growers, thus increasing the difficulty of obtaining reliable estimates on the destructiveness of this disease.

It is generally considered that canker is one of the commonest and most troublesome diseases of the apple, although its destructiveness is not uniform in different parts of the country. According to Shear (1913: 81–82), the black rot disease of apple is found in Europe from Italy to England; yet he states that noticeable injury from the disease in orchards has never been reported. On the other hand, Griffon and Maublanc (1910:308) state that in France the injury may be very serious. In contrast to the general situation in Europe, it may be noted that the damage done by this disease in America is great.

NATURE OF LOSSES

INJURY TO FRUIT. Whenever pome fruits are attacked they are rendered worthless so far as their market value is concerned. The extent of injury may be small while the fruit still hangs on the tree, but ultimately in storage complete destruction is likely to result. Brooks (1909) states that in New Hampshire the black rot is very common and does considerable damage in cellar storage. Burrill and Blair (1901:2) report "great loss at times" in Illinois, and Clinton (1902), in the same State, compares the importance of bitter rot and black rot of apple. The latter he regards as likely to occur in every orchard to some extent. In Kentucky, black rot of apples is regarded as the commonest of fruit rots, according to Garman (1895:127). Stone (letter to the writer) estimates that in Massachusetts from eighty to ninety per cent of fruit rots is black rot. Evans (1910) reports a case in which rotting and mummified pome fruits appeared in a shipment to Cape Colony, and states in this regard:

> During the past three months four hundred and ninety-eight cases of apples and pears in this condition from Cape Colony have been detained, and in order to safeguard the interests of Transvaal fruit growers, the Government, under Government Notice No. 569, of 18th June, 1908, have warned importers of fruit that all consignments of pomaceous fruits found infected with this fungus to the extent of one per cent and upwards will be destroyed upon arrival in this Colony or returned to the consignor.
>
> There is no reason to suppose that this number by any means represents the total amount of diseased fruit that has reached the Transvaal, to say nothing of the other parts of South Africa.

INJURY TO FOLIAGE. The damage to foliage depends on the extent of the infection. In the milder cases the injury is not appreciable. In the more severe cases, partial or even complete defoliation may occur from six weeks to two months before the ripening of the fruit, as a result of which the fruit either drops from the tree or remains small and is of poor quality. In such cases the fruit buds are so weakened as to decrease the possibility of a crop the following year; and the vitality of the trees is impaired. Alwood (1892:62) estimates a loss of seventy-five per cent of the foliage in a part of an old orchard in Virginia, while Stewart (1896) reports a case of complete defoliation of some trees on Long Island by the first of July. It is interesting to note, for comparison, that in 1900, in West Virginia, the disease was regarded by Corbett (1900) as more injurious to foliage than either blight or scab. Scott and Rorer (1909:10–11) have observed a case in which, as they believe, the pathogene causing this disease assisted in the killing, in late summer, of a large proportion of the fruit buds of the apple. They state that on Winesaps it would seem the pathogene alone is capable of killing the buds. Further investigation is deemed desirable by these writers.

INJURY TO LIMBS. As a rule the canker is confined to the orchard, although Wilson (1913) says that young nursery stock may be killed. Bethune (1909:28–29) reports that cankers cause a great amount of damage in Ontario, Canada. J. W. Eastham (letter to the writer), of the Ontario Experiment Farm, states that this is the most prevalent canker in the region east of Toronto, and according to Brooks (1909) it is the commonest canker in New Hampshire. Warren and McCourt (1905:341) refer to this form of the disease as causing more loss in Wayne County, New York, than any other disease except scab. They report it as very serious in fourteen per cent of the orchards; and as doing considerable damage in nineteen per cent of them. In Niagara County, New York, Cummings (1909:304) found canker affecting the orchards as follows: slightly, sixty-one orchards; considerably, sixty-three; seriously, thirty-seven. Paddock (1899 b:181, 188) cites a case in which, in an apple orchard of 80 acres, the trees on 30 acres were ruined and had been taken out; the trees on the remaining 50 acres were then of little value.

In one apple orchard of three hundred and fifty trees under the writer's observation, a count made in August, 1913, showed about thirty-three per cent of the trees (Baldwin, Hubbardston, and Northern Spy varieties) with from one to three dead limbs each. On examination of the dead limbs the New York apple tree canker was found to be present on all. It was further observed that the pathogene causing the infection had lived over winter and had spread to such an extent that girdling had resulted and the foliage had turned yellow and wilted. The fruit on such limbs soon shriveled and was lost. A careful count showed that approximately ten or twelve barrels of fruit were rendered worthless. The loss here might be placed at approximately twenty to twenty-five dollars, or about seven cents a tree. According to the United States Census for 1910, there were in New York, on the 168,667 farms reporting, 11,248,203 apple trees of bearing age.[3] On this basis, assuming the losses in the above-mentioned orchard to be an average, the apparent annual loss would be about three-fourths of a million dollars for a single season in New York State. Many cases can be cited in which the infection by New York apple tree canker is very much more severe, while few orchards in the State, regardless of their careful management, are entirely free from the disease.

Epiphytotics of this disease, such as have recently been experienced in the case of the chestnut blight, are of rare or unknown occurrence. It is characteristic of the disease to take a constant toll year after year, like the cereal smuts. To the losses so incurred must be added the cost of growing diseased limbs. In many cases these limbs die, resulting in the cost of their removal and destruction, which possibly does not seem great in a given year but is not negligible in the aggregate.

SYMPTOMS

ON THE FRUIT

The disease on the fruit is primarily a ripe rot, but it may appear several weeks before maturity of the fruit. It may begin anywhere on the surface or at the blossom end. Frequently the lesions are centered about an injury such as that caused by insects or hail (Plate VII, 1).

Usually there is only one spot on a fruit. The skin at first becomes brown in a small area, but later darkens, finally turning black. On green fruit the affected part may turn black before enlarging to any great extent, whereas on fruit that is ripe or ripening, the whole may be involved before it darkens appreciably. Often concentric bands of uniform breadth and of slightly different shades of color appear about the center of the lesion. The affected area is distinct from the healthy part, and the diseased tissues are not of unpleasant taste as in many fruit decays. Later stages in the development of the rot show a shriveled and much wrinkled surface, which typically becomes covered with black pustules (Plate VII, 2). These characters may be assumed within a month or in less time. Ultimately a dry mummy is produced, which may hang to the tree for a year or more.

Black rot has been confused with brown rot and bitter rot, and even with soft rot. The brown rot disease produces a smooth, coal black, and shiny mummy, which is much less wrinkled than the black rot mummy. Bitter rot, in addition to its unpleasant taste, often shows pinkish specks in a localized region near the center of the lesion. The softening of the pulp in soft rot is not characteristic of black rot specimens. Perhaps the most distinctive characters of black rot are the long duration of the plumpness and juiciness of the tissues, and the occurrence of the above-mentioned black pustules. Under certain conditions the surface of the apple fruit also becomes studded with white tufts; but these are not commonly found and are not to be regarded as a diagnostic symptom.

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[3] Bureau of the Census. Thirteenth Census of the United States taken in the year 1910, 7:195. 1913.

Fruits of the pear and the quince affected with black rot finally become dry and hard. In storage the peach becomes waxy when affected with the disease, according to Baccarini (1890:67).

ON THE LEAVES

The foliage of the apple is more frequently attacked than that of the pear and the quince. The spots usually appear about the time the leaves open. Alwood (1892:62) notes this date as being about May 1 in Virginia. He records a second attack which becomes evident about June 20, and a third outbreak the last of July. Brooks and DeMeritt (1912:181) state that in New Hampshire apple leaf spot appears soon after the leaves unfold from the bud. In western New York spotting is more commonly apparent in July and August. The writer observed spots developed in September, 1913, at Byron, New York.

The number of lesions that may appear on a single leaf varies from one to several, and these may be scattered or localized on the surface (Plate VII, 3). The first evidence of a spot is a minute purple speck, which soon enlarges until it has reached a diameter of from two to ten millimeters, averaging about four millimeters. The purplish color is maintained for a considerable time, during which the margin is somewhat indefinite. Later the lesion is of a yellowish brown color and the spot assumes a more or less circular shape, while the margin becomes more definite. Still later the margin becomes elevated and the diseased area sunken. As the spots grow older they become lobed, due to a secondary extension of the pathogene from one or more points, and finally a series of more or less concentric areas produces an irregular blotch in which the outline of the original spot can be recognized. The center has now become grayish brown, and the entire lesion presents an appearance which has given rise to the name *frog-eye*.

The spots on the lower surface seem to enlarge as rapidly as those on the upper, but they are not so conspicuous. Sometimes the center of the spot on the lower surface is grayish brown. The whole diseased area may, however, merely appear dark and indefinite.

Frequently small, black, dome-like bodies are found on the upper surface of the leaf, usually toward the center of the lesion. In severe cases the leaves turn yellow and fall from the tree. According to Brooks and DeMeritt (1912:181), this leaf fall occurs from six to eight weeks earlier than would happen normally. Reed, Cooley, and Rogers (1912:3) maintain that defoliation may occur early enough for a new crop of leaves to be put forth the same season. Trees robbed of their foliage from year to year must eventually become greatly reduced in vitality and finally succumb to a premature death.

Bordeaux injury is sometimes very similar to frog-eye leaf spot; Brooks and DeMeritt (1912:190) state that this is especially true if rains follow the application. Kinney (1895 b) notes also that injuries from the leaf miner (*Tischeria malifoliella* Clemens) are sometimes mistaken for leaf spot.

ON THE LIMBS

In western New York, young spots may be found on the bark at any time from the last of April until toward the close of the growing season. Numerous young cankers have been observed on Twenty Ounce trees in Monroe County orchards during the month of August. It is the rule that the larger limbs are much more susceptible than the twigs, and the trunks show comparatively few lesions. The cankers on the trunks occur more or less uniformly on the southwest side of trees. The limbs more commonly show the diseased spots on the upper side. Lesions are very often found about the base of a small limb or about a wound in the bark.

In the earlier stages of the formation of a canker, the bark is slightly sunken (Plates VIII, and IX, 4) and reddish brown in color. The diseased area slowly increases in size and darkens, and, although not conspicuous at a distance, the spot is readily distinguished from healthy tissue on closer examination. Some lesions remain very small, measuring only a few centimeters in their longer diameter; in such cases the canker usually dies out at the end of the year. Where the injury is larger, the diseased spot enlarges from year to year for a distance of a meter or even more.

It is often observed that a canker is merely a superficial roughening of the bark. In other cases the bark is killed to the wood and becomes conspicuously cracked (Plate X).

The discolored area may extend over a considerable surface; or, regardless of its size, a crevice may appear at the margin, limiting, temporarily at least, the extent of the lesion. Further spread of the pathogene results in the formation of a prominent spot, which soon forms a second line of demarcation between the healthy and the diseased tissue. Repetition of this process from one or more points at the margin occurs, thus producing a lobed appearance (Plate XI, 2); or the spreading may arise from all points about the first marginal crack, so that a series of concentric crevices is developed, as described for frog-eye of the leaves. The bark remains closely appressed to the wood for at least a year; later the dead bark cracks and falls away, exposing the wood and a callus around the margin of the wound (Plate x, 3).

Cankers that begin to form early in the season show numerous fruiting pustules of the pathogene scattered over the central area of the spot. These may not become evident, however, until the second season.

Large limbs are rarely girdled the first year; the girdling comes about by the enlargement of the canker the following season. Complete encircling results in the death of the parts above the canker, as evidenced by the yellowing and dropping of the leaves (Plate xii, 1) and the shriveling of bark and fruit. It is not uncommon in such cases to find the fruit clinging to the twigs for a year or more.

Clinton (1907) describes a peculiar type of lesion on apple limbs. He says, in part:

> Another and more peculiar feature of the trouble was the enlargement of the limbs into somewhat fusiform swellings, as shown in the illustration. In some cases several of the swellings followed one another on the same limb. These enlargements generally showed a greater swelling on one side than on the opposite, and often the bark was split down the more swollen side. Cross and longitudinal sections showed that the swellings were apparently the result of severe cold, which had injured the limbs unevenly along the branch, as shown by the blackened wood on the injured portion.

Delacroix (1903 a: 135) notes a thickening at the base of some cankers. This he finds to be a sort of cushion developed in a transverse direction in the healthy bark. The writer has occasionally observed cankers showing hypertrophy at the upper and lower ends of the diseased part (Plate x, 4).

It is to be noted that on quince twigs the cankers are often very indefinite. A rare specimen is shown in Plate x, 5. The normal color of the bark is not distinctly lighter than that of the diseased part, so that on this host the disease doubtless passes unnoticed in many cases.

OTHER ORGANS AFFECTED

A unique case in Virginia of fall blossoming of the apple following the canker has been described by Reed (1908). This author found normal blossoms on an apple tree in the orchards of the Virginia Experiment Station on October 5. The cankers on the limbs had caused the death of more than half the top of the tree, and many branches, severely affected, had been able to make a very small amount of growth during the season. Reed says: " It was on such branches as these that fruit buds were found open on the above named date. Examination of the blossoms showed that they were normal as regards parts, color, and internal relationships.

I am informed by Professor H. L. Price of the Department of Horticulture of this Experiment Station that this fall blossoming is not uncommon on trees which are badly affected by the black rot fungus."

ETIOLOGY

The pathogene here concerned is the fungus *Physalospora Cydoniae* Arnaud.

MORPHOLOGY

PERITHECIA. The perithecia have been found by the writer on the twigs of apple (*Pyrus malus* L.) and of witch-hazel (*Hamamelis virginiana* L.), and have been described by him in another publication (Hesler, 1913:293). Recently the writer has found the ascogenous form on twigs of white oak (*Quercus alba* L.).

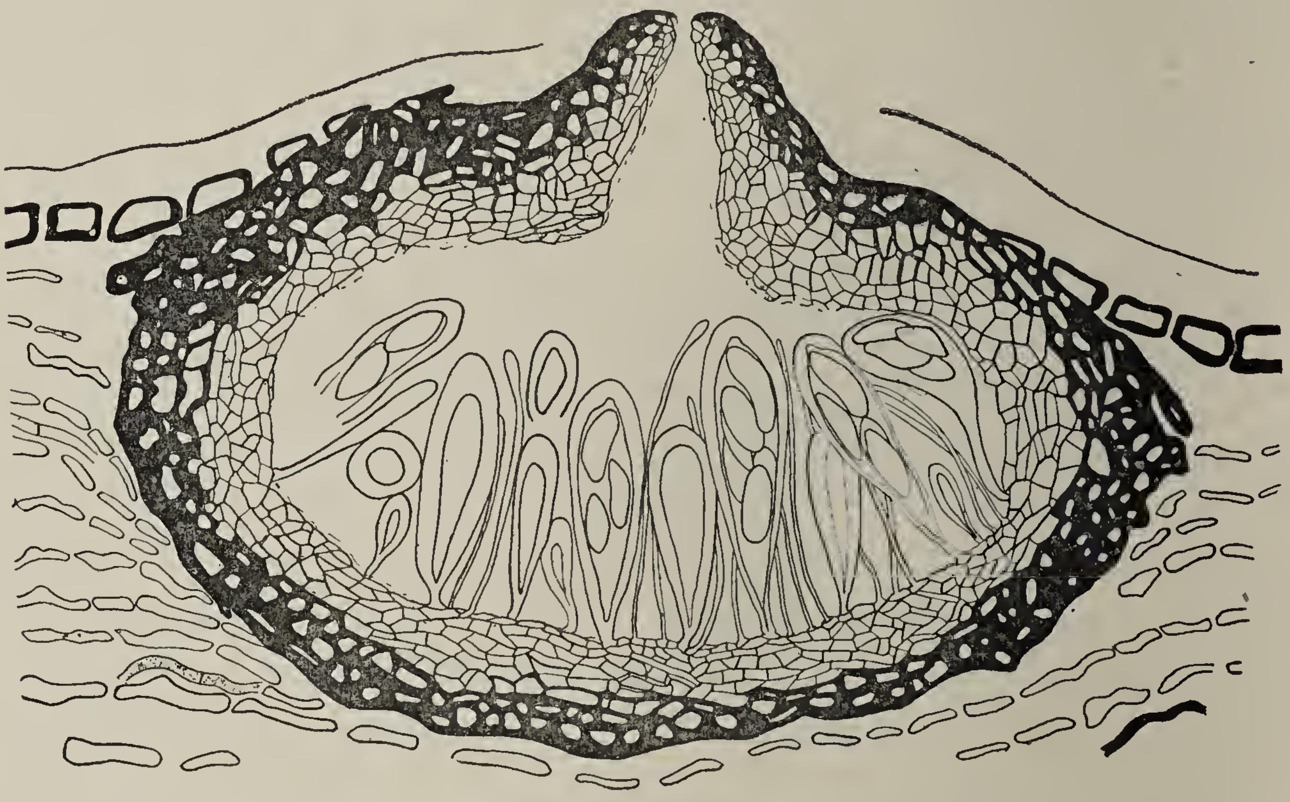
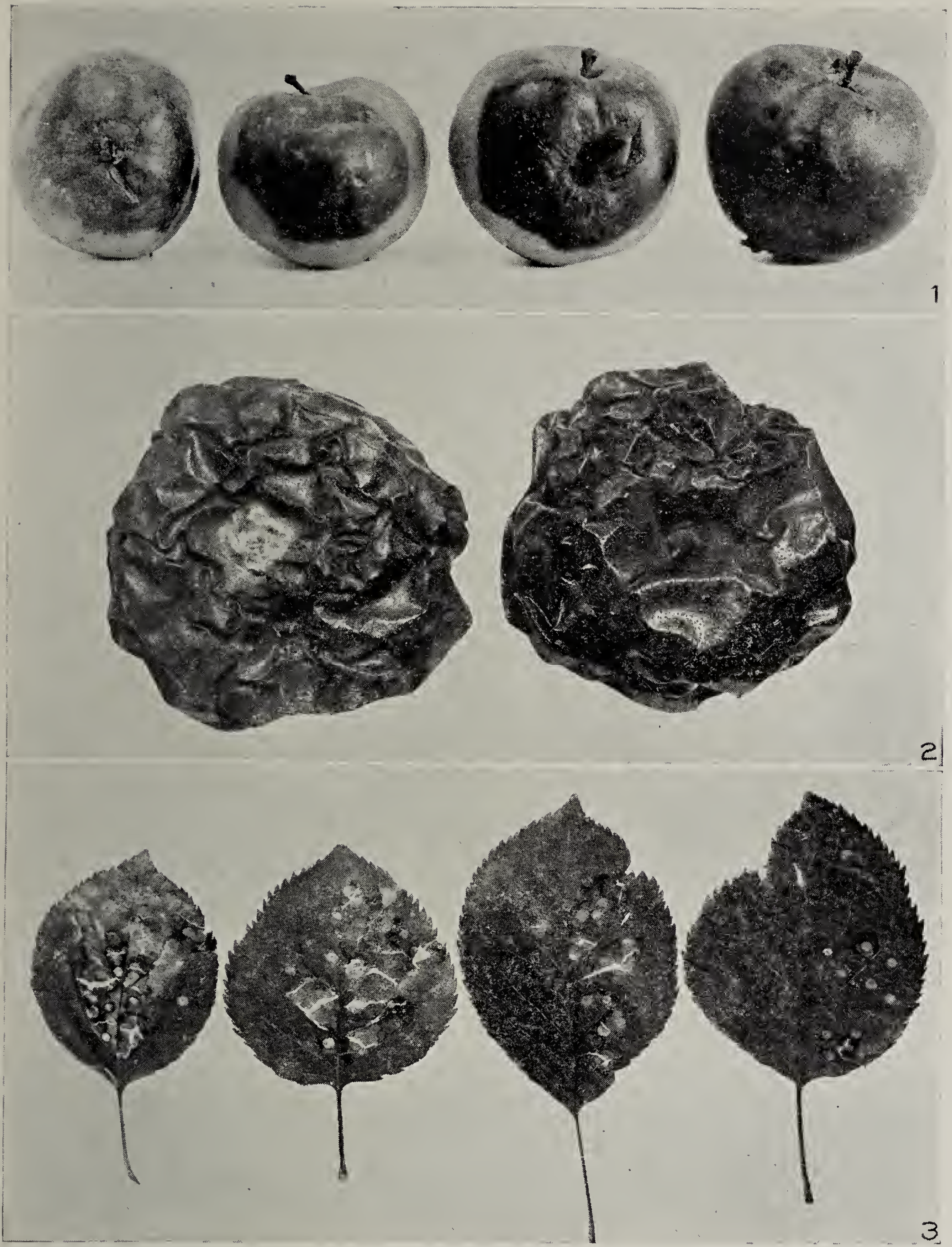


FIG. 18. PERITHECIUM OF PHYSALOSPORA CYDONIAE
Camera lucida drawing of a median longisection of a typical perithecium

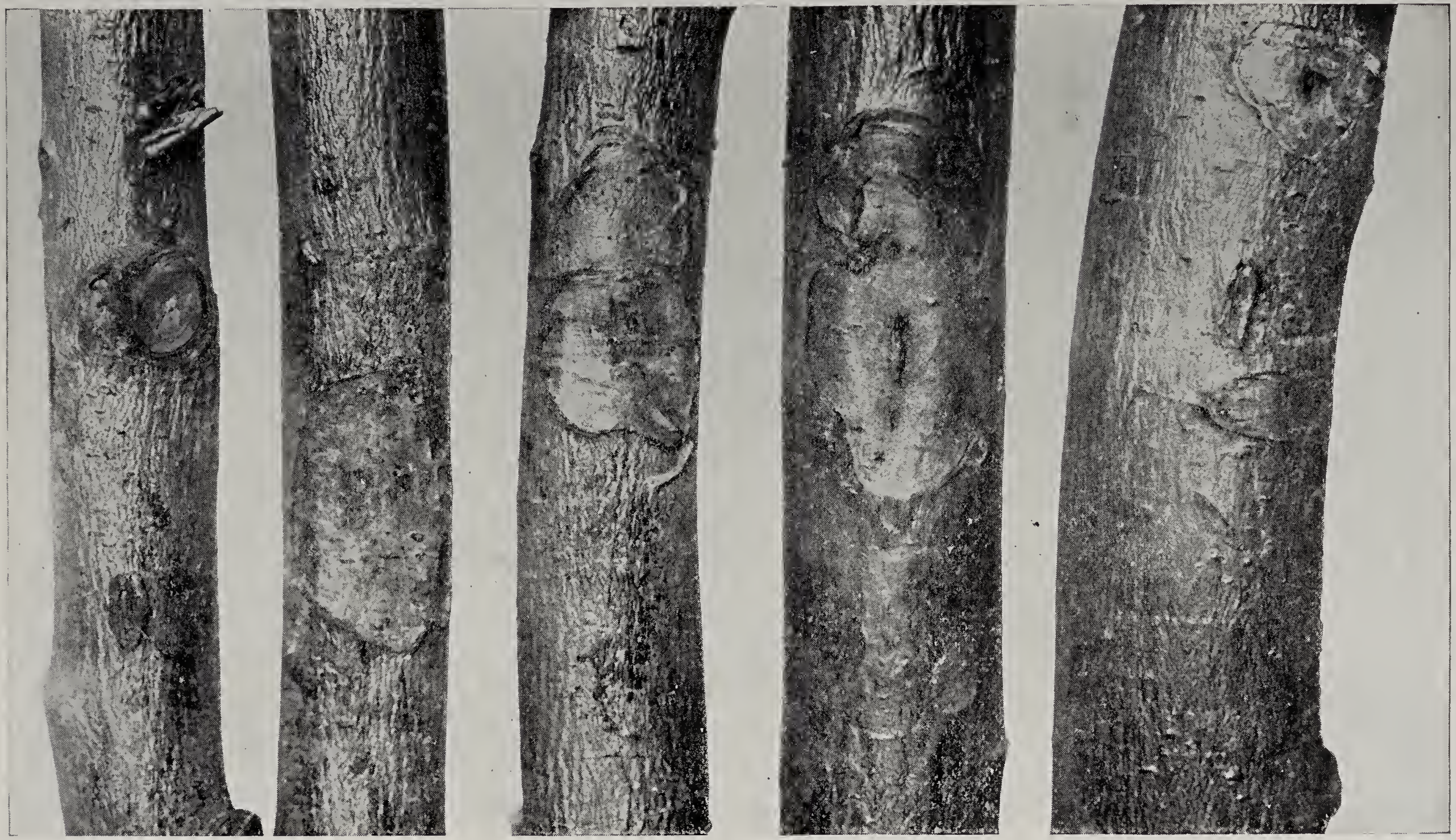
The perithecia are usually scattered, standing separate from one another. Sometimes, however, from two to four fruit bodies are joined together, but no stroma has ever been observed. They are buried in the cortical tissues, protruding at maturity by a short, papillate ostiole. Their form is globose to subglobose, measuring from 180 to 324 μ in the vertical diameter by 300 to 400 μ in the horizontal diameter, averaging about 225 by 325 μ.

A typical perithecium is shown in figure 18. The wall is differentiated into two layers. The thickness of the outer layer varies slightly with the sides and base of the perithecium, and the pseudo-cells are thick-



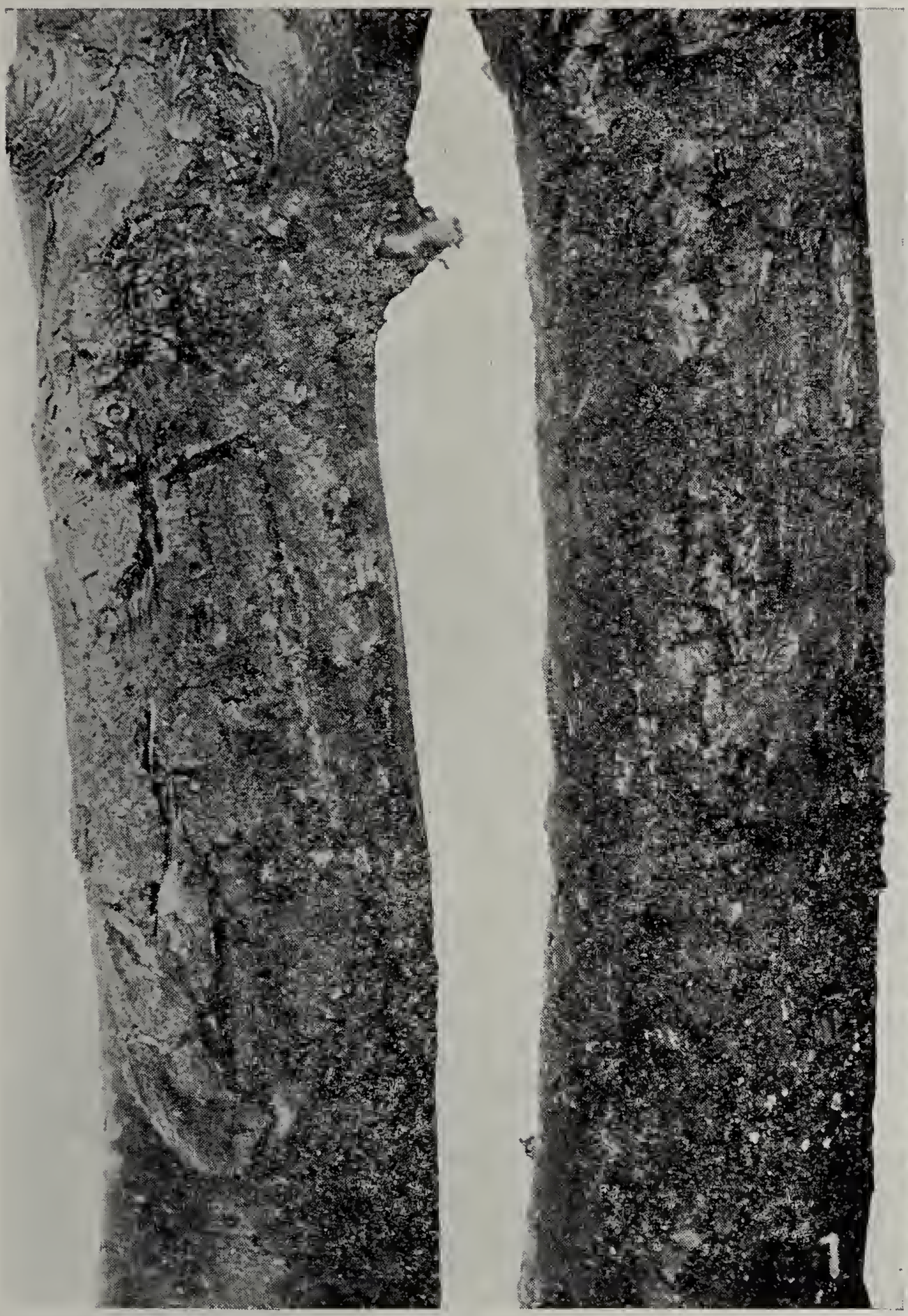
SYMPTOMS OF THE DISEASE ON FRUIT AND FOLIAGE

1. Types of infection on apples, early stages
2. Apples reduced to mummies as a result of the disease
3. Types of infection on apple leaves as commonly found in New York State



INOCULATION EXPERIMENTS ON APPLE

The specimen on the left is a check; the next three show cankers resulting from infections by ascospores from apple; the specimen on the right was inoculated with ascospores from witch-hazel, and in this case infection did not occur. Date of inoculation, July 16, 1913; photograph made September 20, 1913



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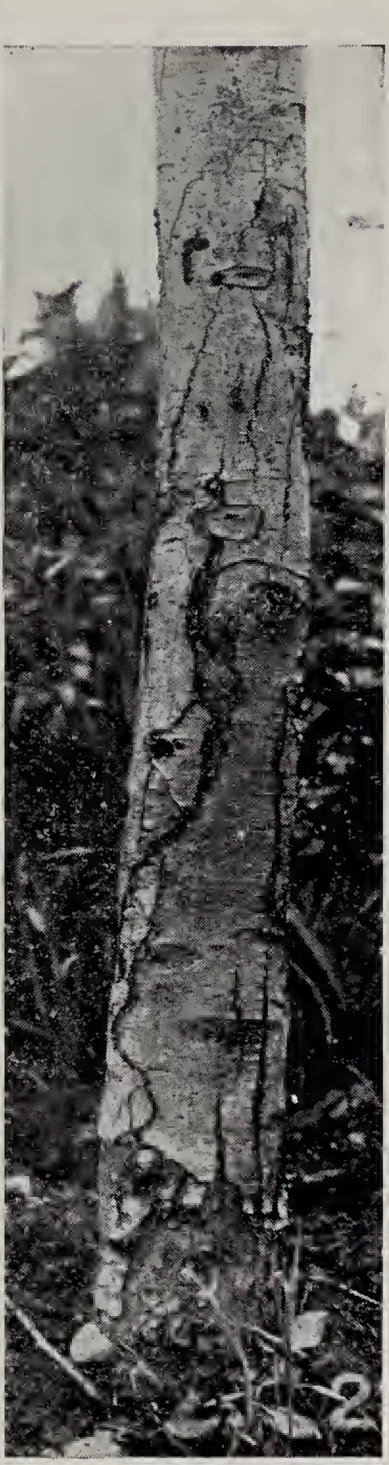

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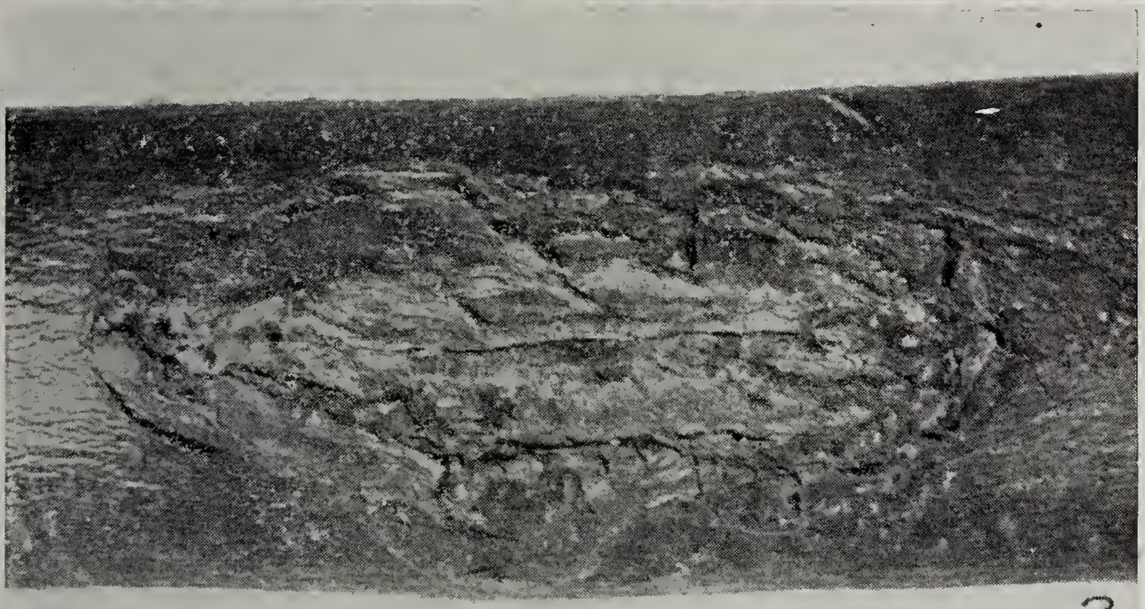

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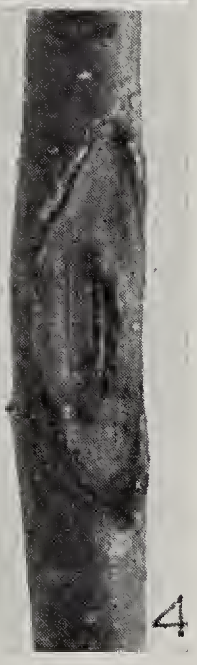
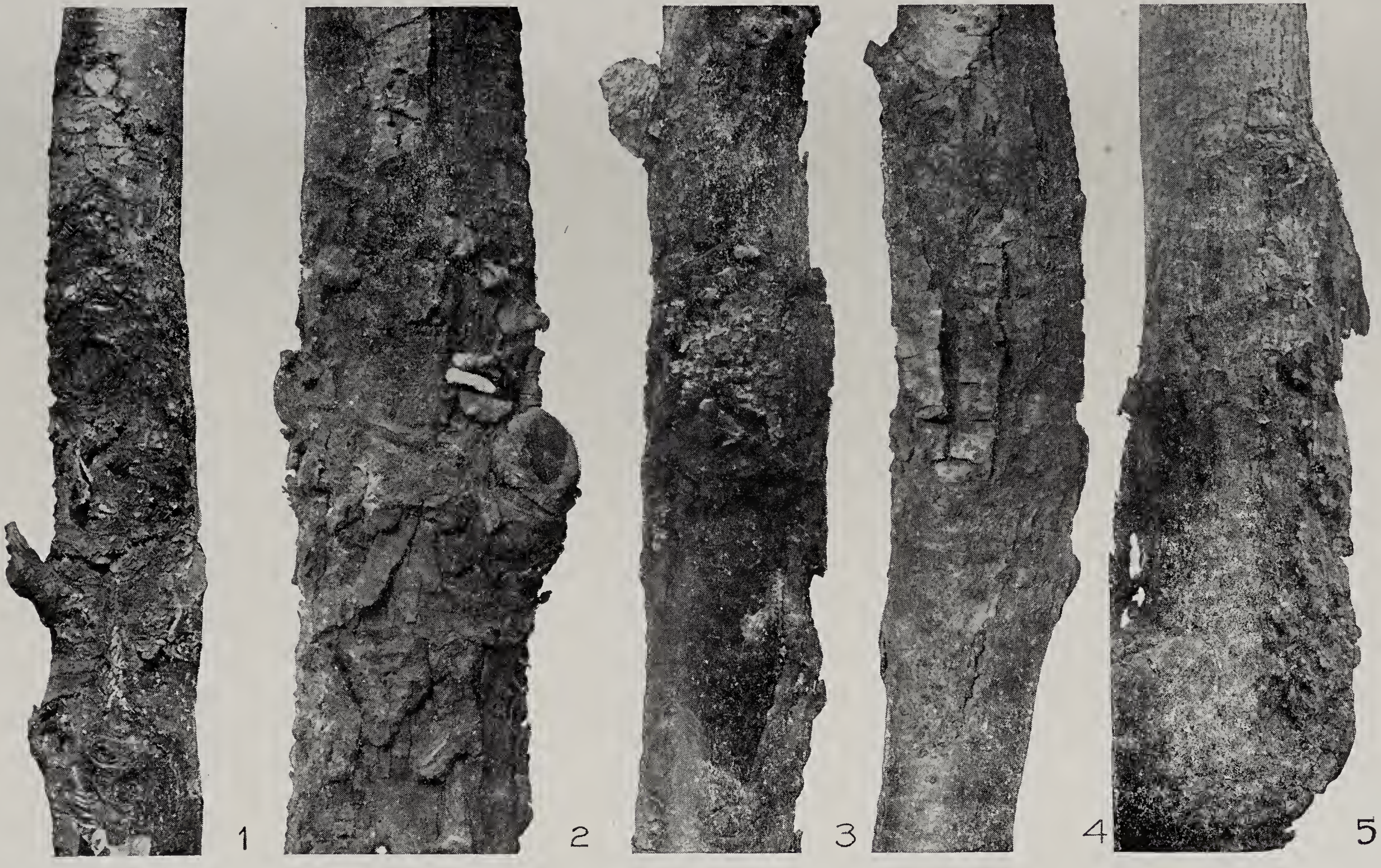


4

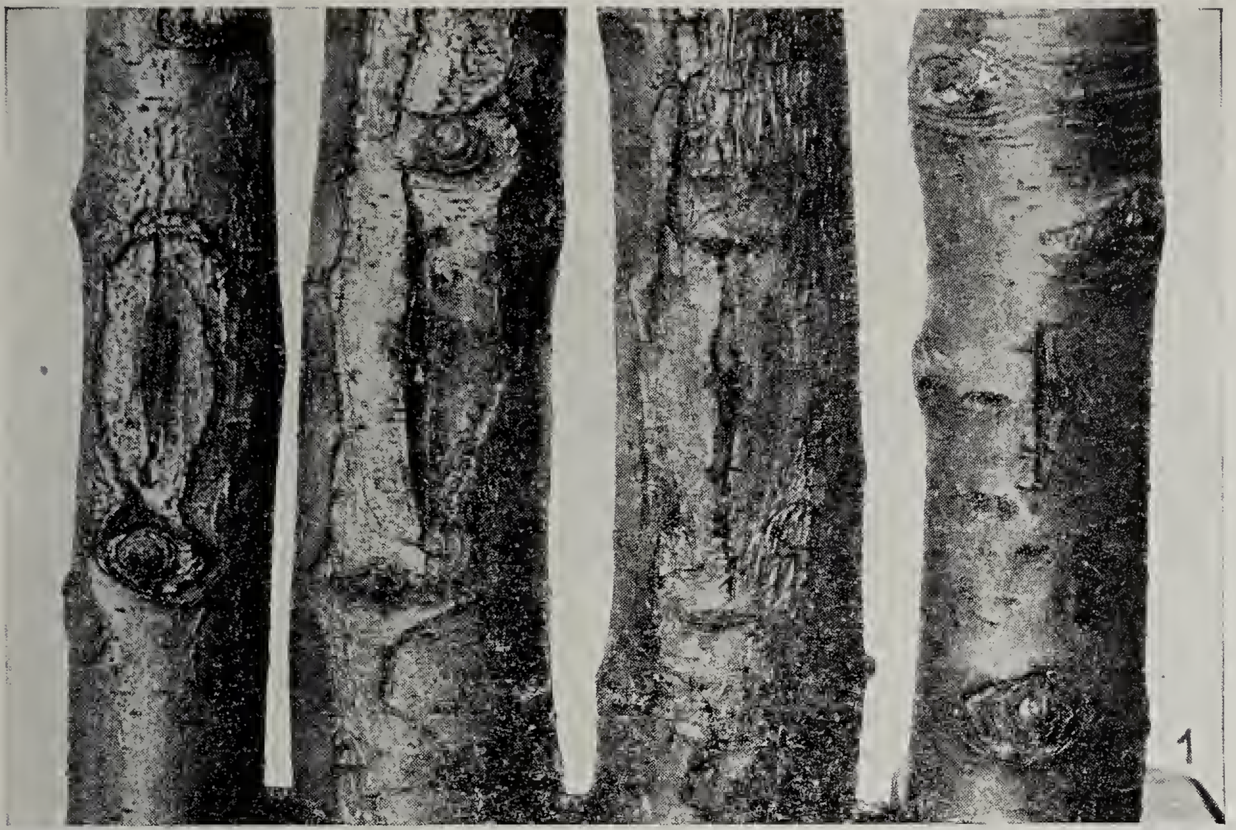
NATURAL CANKERS AND CANKERS PRODUCED BY ARTIFICIAL INOCULATION WITH PHYSALOSPORA CYDONIAE

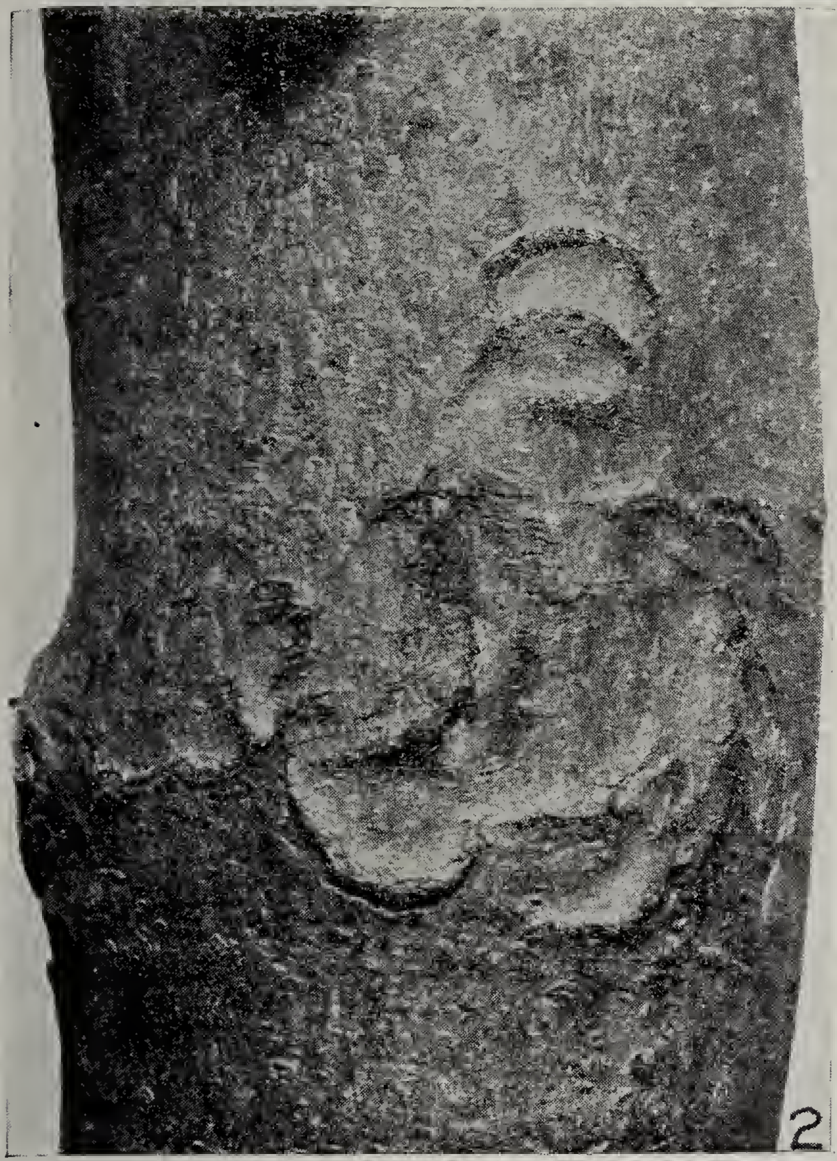
1. Natural infection on the left; artificial infection on the right. The latter inoculated on July 1, 1913, with a strain from Twenty Ounce apple bark. Photograph made September 30, 1913
2. Canker on trunk of mature pear tree. Inoculation made July 18, 1910, photograph made September 1, 1911
3. The result of inoculation by use of pycnospores from apple leaves. The healing process has occluded the wound before the pathogene could produce a large canker. Inoculation made July 1, 1912, photograph made September 20, 1913
4. Canker on Baldwin twig produced artificially, using ascospores from apple. Inoculation made July 25, 1914, photograph made December 10, 1914

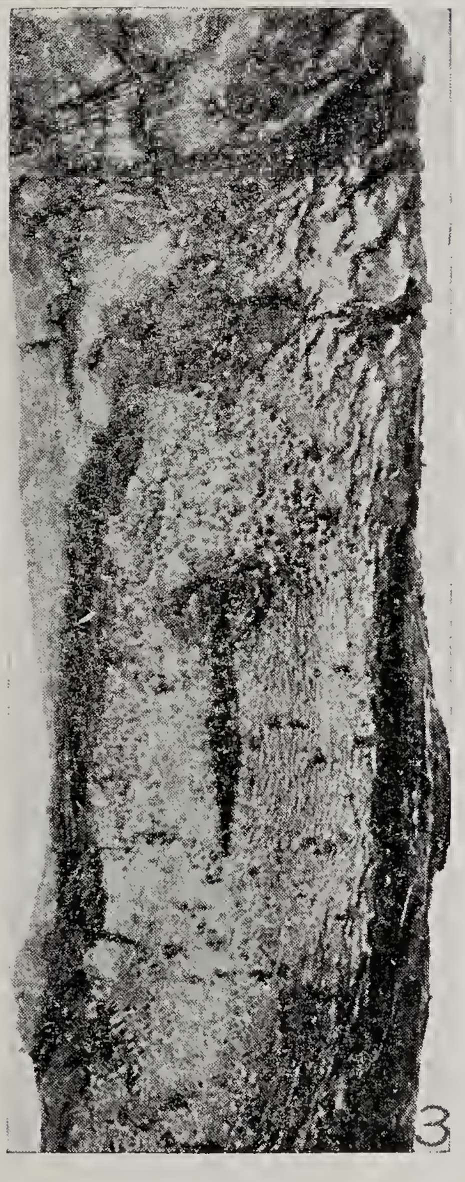


SYMPTOMS OF THE NEW YORK APPLE TREE CANKER

1. Typical old and much-roughened canker on Twenty Ounce apple. The bark is still clinging
2. Old canker on apple, showing roughened surface. Some of the bark has fallen from the lesion
3. Old canker on apple, showing callus about the margin. Note that most of the bark has sloughed off
4. Cankered limb of apple, showing hypertrophy toward the upper end of the lesion
5. Canker on quince





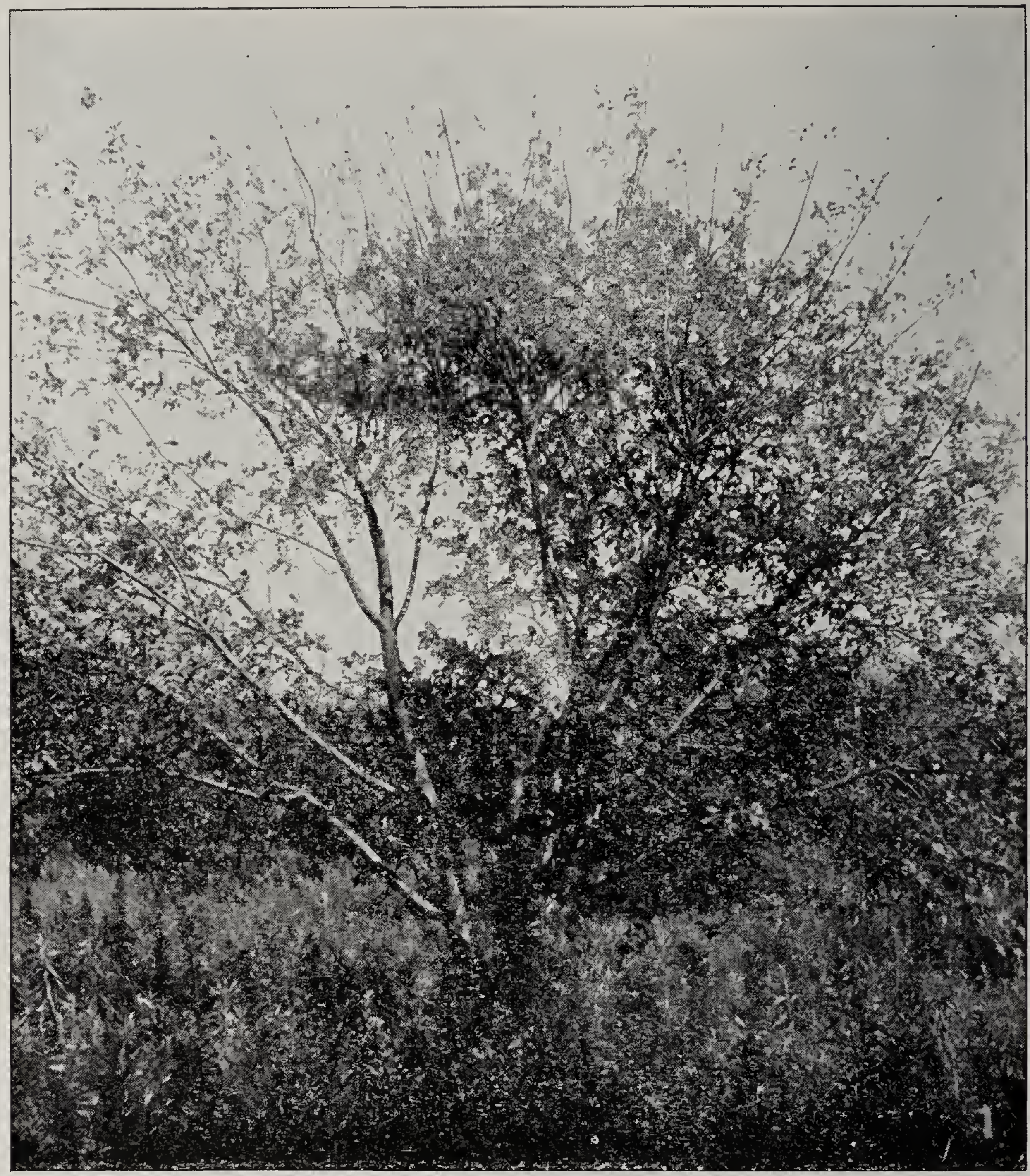


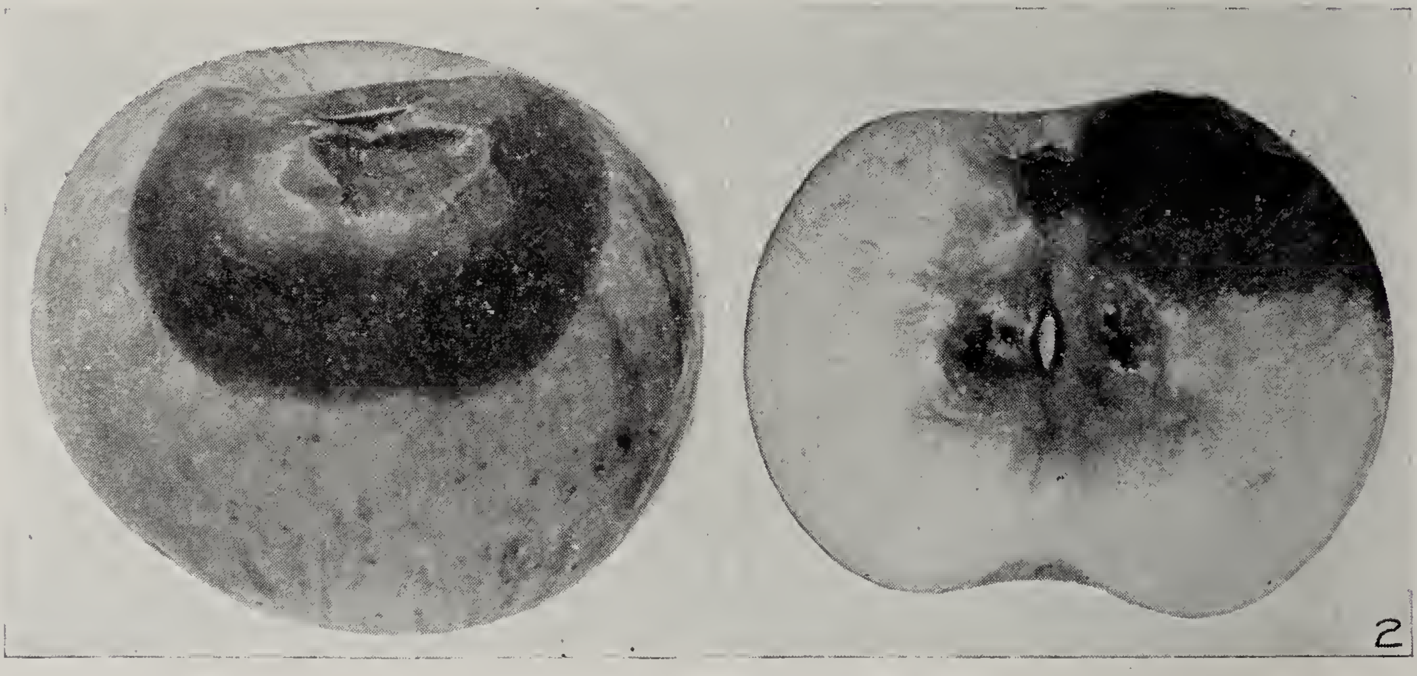
INOCULATION EXPERIMENTS WITH PHYSALOSPORA CYDONIAE

1. The three cankers on the left produced by inoculating pear with ascospores from apple. Check on the right. Inoculations made June 6, 1913, photograph made September 20, 1913

2. Canker on Twenty Ounce limb produced artificially, using pycnospores from apple. Inoculation made June 20, 1912, photograph made September 20, 1913

3. Canker produced on pear by inoculation with ascospores from apple. The presence of pycnidia should be noted. Inoculation made June 6, 1913, photograph made September 20, 1913

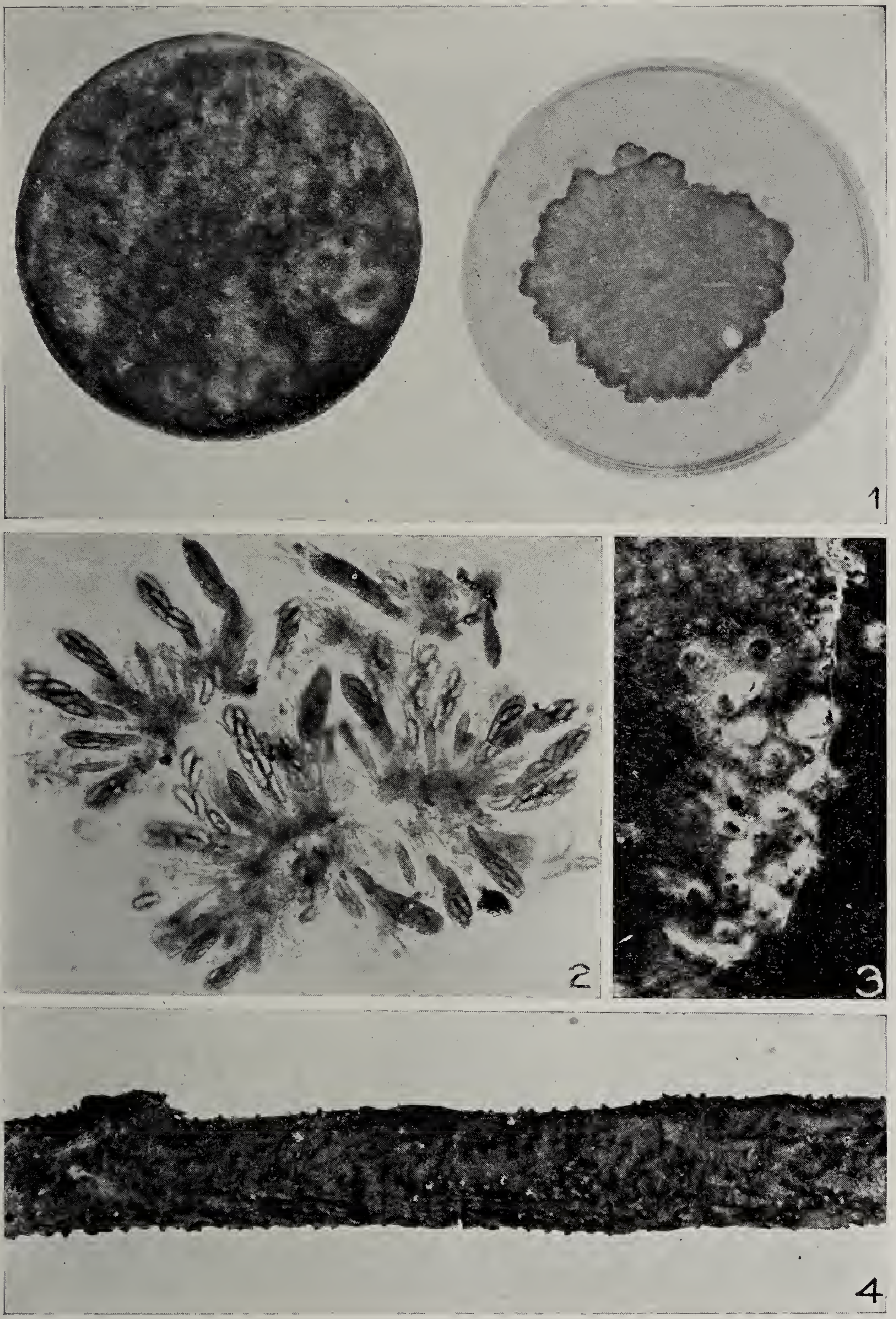




NEW YORK APPLE TREE CANKER

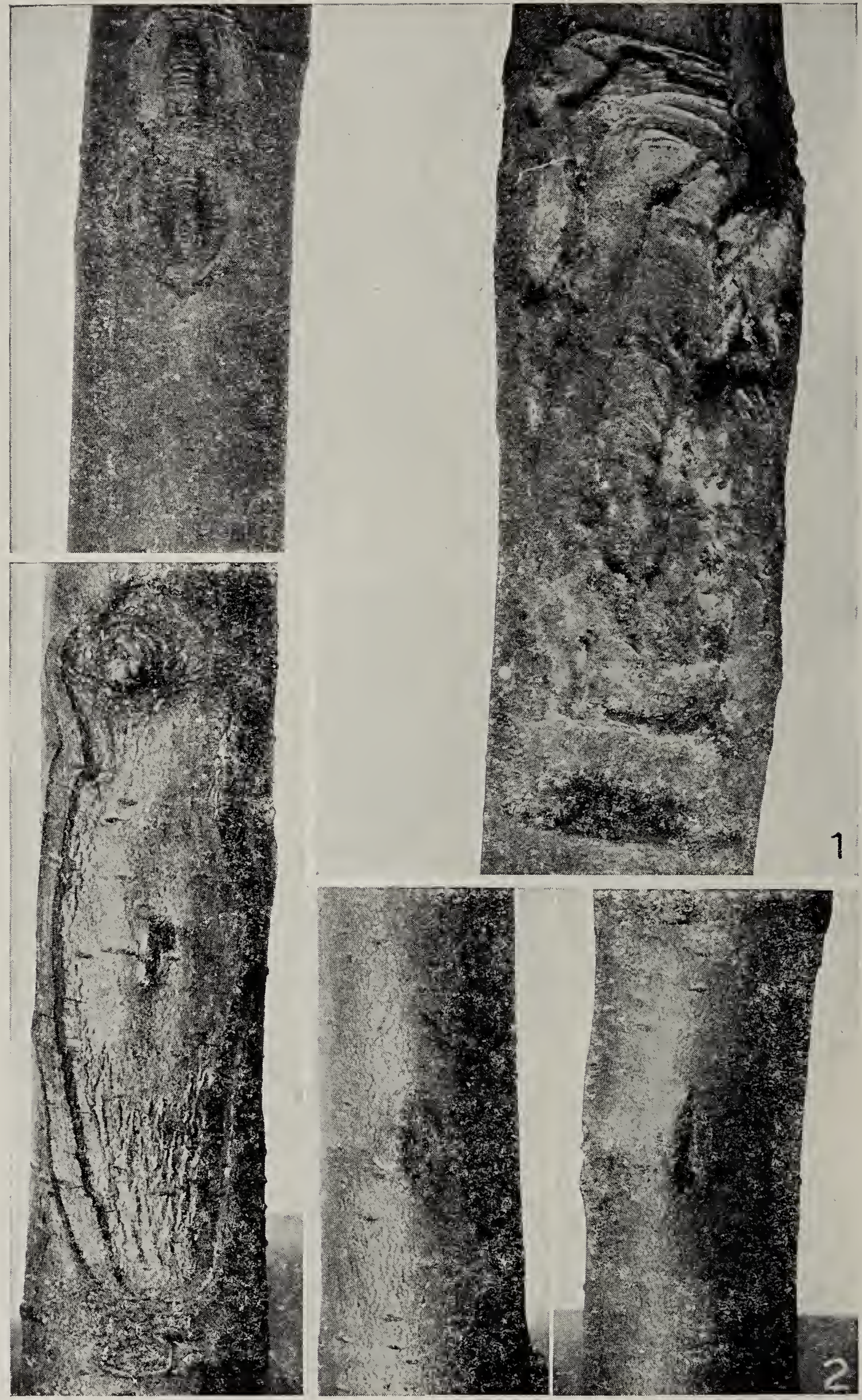
1. Twenty Ounce apple tree, some of the larger limbs of which have been girdled by the fungus. Evidence that this has occurred is found in the defoliated tops of affected limbs

2. External view at left, and internal view at right, of young black rot lesions on apple; the specimen on the right shows the tissues involved



VARIOUS STAGES OF PHYSALOSPORA CYDONIAE

1. Showing differences in growth on nutrient agar from pycnospores (heavy dark growth on left) and from ascospores (scant growth on right)
2. Photomicrograph of asci, ascospores, and paraphyses from a single perithecium
3. Sclerotia as they appear in pure culture
4. Twig of apple, showing dark masses of pycnospores which have oozed from the pycnidia when the twig was kept in a moist chamber



INOCULATION EXPERIMENTS WITH PHYSALOSPORA CYDONIÆ

1. Canker on right, check on left. Inoculation made July 1, 1912, using pycnospores from pear, the fungus having followed fire blight. Photograph made September 20, 1913

2. Comparison of two different apple strains on pear. Specimen shown on left inoculated with ascospores from apple. Specimen shown in center inoculated with pycnospores from apple, following fire blight. The very slight infection should be noted. Check on right. Inoculation made June 6, 1913, photograph made September 20, 1913

walled. The inner, thin-walled layer is of very uniform diameter. In cases in which the perithecium is depressed, the outer layer is reduced at the base and is from one to three pseudo-cells in thickness, whereas the lateral outer walls are from two to five layers of pseudo-cells in thickness. The ostiole appears as a narrow passage in the papilla, the walls of which show the same distinct layers as those just described for the sides and base of the perithecium.

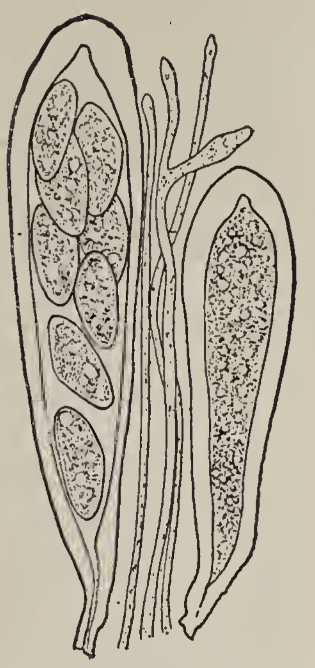


Fig. 19. asci and paraphyses of physalospora cydoniae

Camera lucida drawing of asci and paraphyses, showing structure of the latter and typical arrangement of ascospores in the ascus

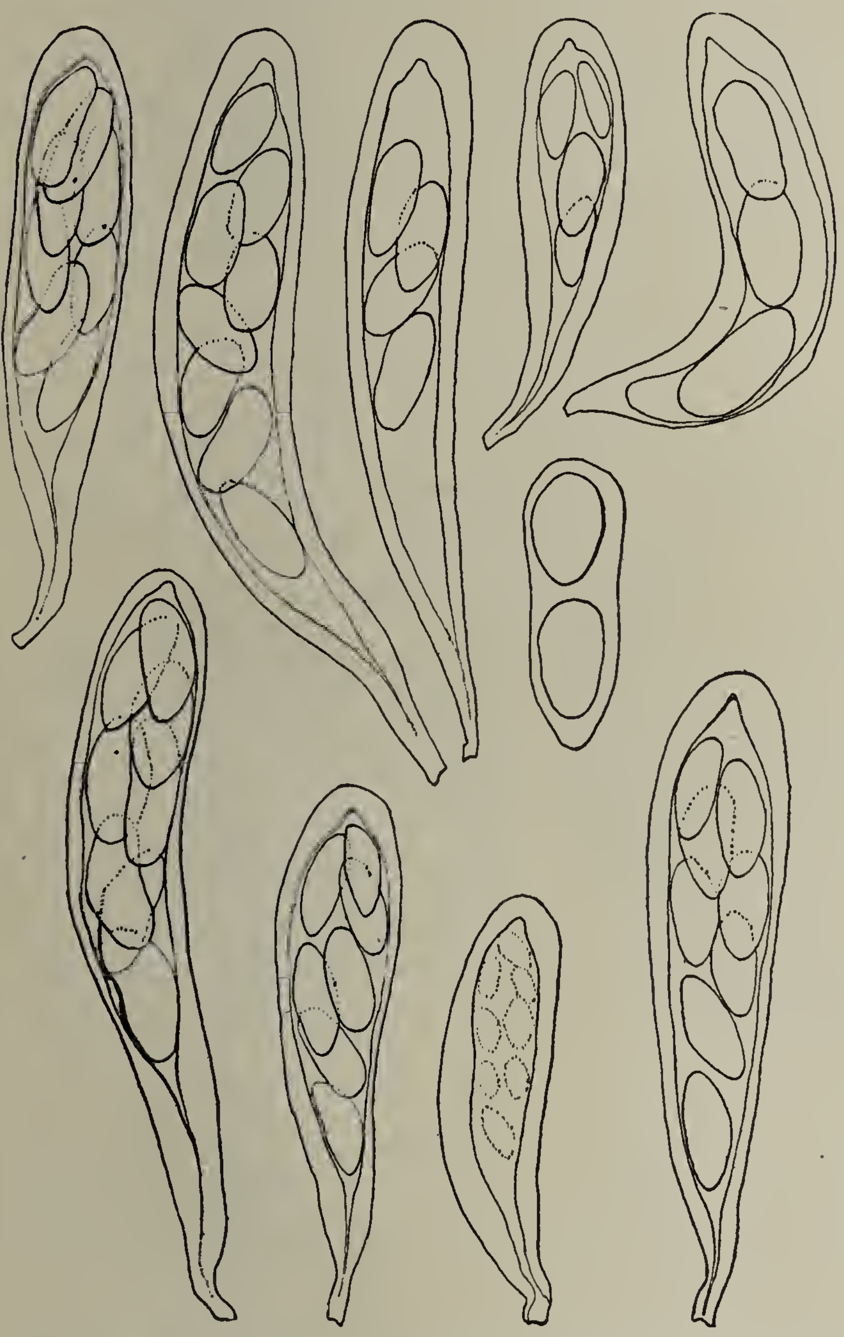


Fig. 20. asci of physalospora cydoniae from different hosts

The upper series represents variations as found on apple bark. The lower series shows variations from bark of witch-hazel

The asci, with the interspersed paraphyses, usually fill the cavity of the perithecium. Arnaud (1912:11) states that in general the paraphyses are formed by rows of cells which in the mature perithecium are separated one from another in the form of distinct filaments. He says that in certain cases, however, the paraphyses remain agglutinated by their walls and appear in section like rows of cellular cavities, as in Cucurbitaria (*C. Spartii* and other species). He explains that if the rows of cells are not very numerous the existence of the paraphyses may become uncertain. Arnaud finds this the case with *Physalospora Cydoniae.* The writer, however, has not observed this condition of the paraphyses; to him they appear distinct and non-septate (Fig. 19).

The asci are abundant; asci crushed from one perithecium are shown in Plate xiii, 2. They are usually clavate, although they sometimes tend to be cylindrical, measuring from 21 to 32 μ by 130 to 180 μ. The tip of the ascus is thickened, but a complete canal from the inner wall to the outside has not been observed; only a suggestion of such a canal has been seen even after the perithecia had been kept in a moist chamber for several hours. Variations of asci from different hosts are shown in figure 20.

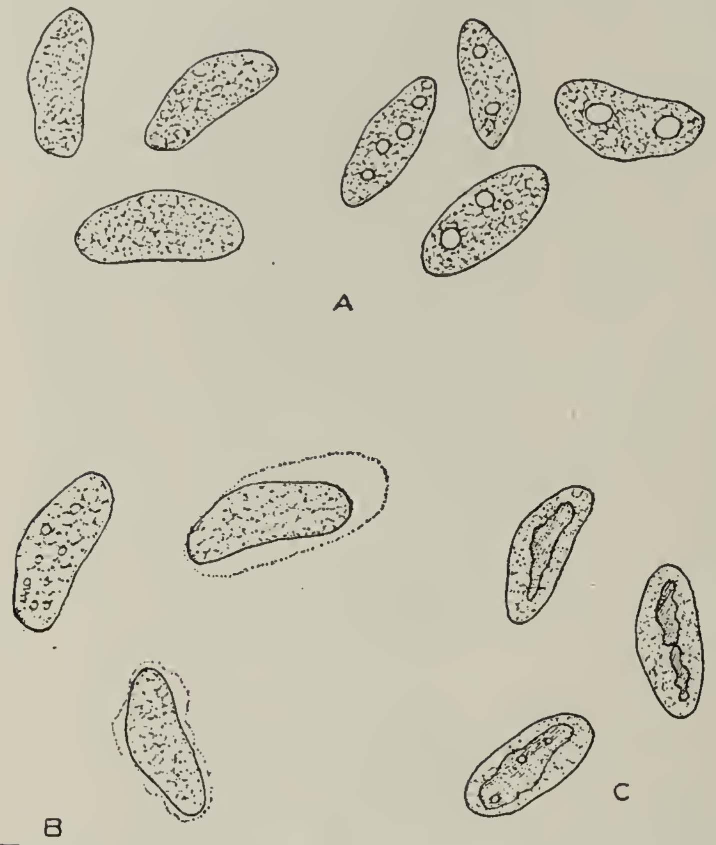


Fig. 21. TYPES OF ASCOSPORES OF PHYSALOSPORA CYDONIAE

A, Typical mature ascospores as found in nature; B, ascospores, showing stages in the development of the gelatinous sheath; C, old ascospores, showing peculiar contents

The ascospores are ellipsoidal, or often inequilateral (Fig. 21); they measure from 10.8 to 15.2 μ by 23.4 to 34.2 μ, averaging 11.5 by 28 μ. They are hyaline to greenish yellow. Under ordinary conditions the spores show a very thin gelatinous sheath, but after they have been in a saturated atmosphere for a few hours the sheath becomes very broad and evident. The arrangement of the spores in the ascus is more or less biseriate. The paraphyses are distinct and are occasionally branched near the tip. Not infrequently the apex shows a tendency to be clavate.

The number of spores in each ascus is typically eight, but exceptions have been found in the fungus on apple twigs. The variation ranges from two to eight spores within an ascus, all intervening numbers having been observed. Four-spored asci are not uncommon (Fig. 20). The contents of ascospores are either densely granular, or vacuolate and oily. Two guttules are occasionally found.

PYCNIDIA. The morphology of the pycnidial form of this fungus is variable (Fig. 22). The pycnidia are situated in the cortical tissues and are usually scattered and distinct, although on the same organ of the host they may be single, confluent, or united into a stroma. The number of pycnidia per unit of area is usually less on woody substrata than on fruits; on apple fruit there may be from one hundred and twenty to one hundred and fifty pycnidia per square centimeter.

The typical simple pycnidium (Fig. 22, A) measures from 200 to 300 μ in each diameter, whereas the compound fruit body may vary from 200 to 460 μ in the vertical diameter and from 200 to 720 μ in the horizontal diameter (Fig. 22, G). Their shape is in general the same as that of the perithecia, globose to subglobose, and they have the same distinct outer and inner walls. The thickness of the entire pycnidial wall is variable, as in the case of the perithecium. The basal part is thinner in the case of the subglobose fruit bodies. This condition may be attributed to the fact that less protection is needed at the base; or perhaps here the thickness may be partially determined by mechanical pressure brought about by the resistance offered by the host tissue.

Arising from the inner thin-walled cells are the pycnosporophores, which extend entad. They are clavate, flask-shaped, or cylindrical. They may be as long as the spore itself, from 25 to 30 μ, or may measure less than 8 μ; the average dimensions are from 10 to 15 μ by 3 to 4 μ. At the tip of each is developed a pycnospore.

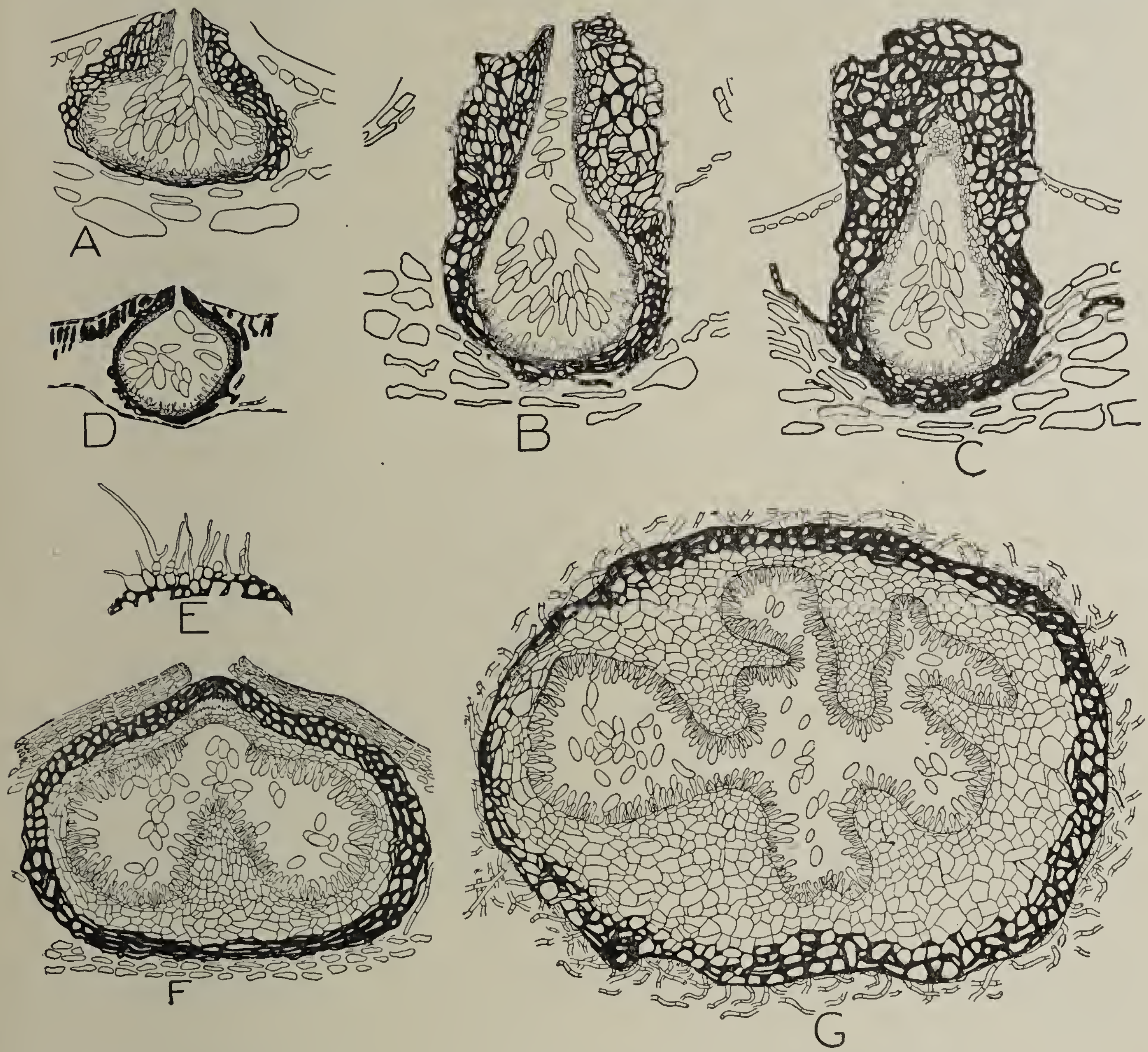


Fig. 22. VARIATIONS OF PYCNIDIA OF PHYSALOSPORA CYDONIAE

A, Typical simple unilocular pycnidium; B, pycnidium with long neck, similar to C but with an ostiolum; C, pycnidium similar to B, ostiolum not yet developed; D, pycnidium from apple leaf; E, hair-like outgrowths on the tip of an ostiolum, developed under moist conditions; F, pycnidium with mound-like structure at base; G, pycnidium which approaches in appearance the fruiting body of species belonging to the form-genus Botryodiplodia

In some cases there is a mound-like structure at the base of the pycnidium (Fig. 22, F). This is illustrated by Duggar (1909: 353, fig. 171). It has been a matter of conjecture whether this may appear only in an oblique tangential section, or whether it is a bilocular tendency. It does not seem possible that any such structure would appear merely in a section that was not cut vertically. If this were true, the question would then arise as to whether this same appearance would not extend at all points along the lining of the cavity, and hence merely make the wall thicker rather than give it the aspect just described. It seems, therefore, to be a bilocular tendency.

Frequently the pycnidium approaches and even reaches the condition characteristic of the form-genus Botryodiplodia (Fig. 22, G). The sporogenous layer extends inward at places, giving the inner wall a corrugated appearance. This condition is found in nature and has been developed in culture from spores in pycnidia which originally did not show this structure. The simplest condition suggesting the form-genus Botryodiplodia is found when a single mound-like structure occurs at the base of the pycnidium, as previously described (Fig. 22, F). Frequently this finds its expression in the form of a bilocular condition, which is a step nearer the Botryodiplodia type.

The ostiolum offers some interesting variations. Miss Walker (1908) describes a form which she believes lacks an ostiolum. In the place of the typical conical ostiolate neck there was found a much-thickened wall at the apex of the fruiting body, and the papilla itself appeared longer than usual. The writer has cultured the ostiolate form from an apple, and has obtained, on various agars and on apple fruit, pycnidia having the characteristics described by Miss Walker (Fig. 22, C). The evidence at hand indicates that a pore may or may not be present, depending somewhat on the time of year and on weather conditions. In any case an ostiolum will ultimately be developed (Fig. 22, A, B, D). Brooks and De Meritt (1912 : 184) report three types of pycnidia but all forms are ostiolate. It does not seem likely that any strain will remain void of an ostiolum throughout its history. A strongly papillate form similar to that shown in figure 22, C, but with an ostiole developed, is illustrated in figure 22, B. A form of the fungus which at first appeared to have a non-erumpent pycnidium was found in apple bark and twigs of *Celastrus scandens* L. After the material had been in a moist chamber for a few days, however, the pycnidia broke through the epidermis.

In conclusion it may be stated that the pycnidia may vary in morphology on different host plants, yet this variation is no greater than that on the same host plant.

PYCNIDIAL FORMATION. The pycnidia arise from the mycelium and are found abundantly on cankers and decayed fruit. Also they may be produced on various artificial media. They occur sparingly on spotted leaves.

So far as has been determined, the process of formation is similar on different substrata. The earlier stages are more accurately followed in agar cultures than on any organs of the host plant. The writer's observations have been made by examining petri-dish cultures under the low power of the microscope and by the use of prepared slides from such cultures. The material was prepared as follows: Pycnospores or hyphal threads were planted in the center of agar plates, and, as the hyphæ developed, pycnidia appeared in more or less definite concentric rings. In this way the oldest pycnidia were nearest the starting point, whereas the youngest were found near the margin of the culture, the stages between the two being intermediate. Blocks of agar were cut out from the dish, fixed, and imbedded in paraffin. A single section frequently includes a gradual series of the several stages, from the very youngest to the more mature structures. The sections were made both perpendicular and parallel to the surface of the agar, the second method proving the more satisfactory.

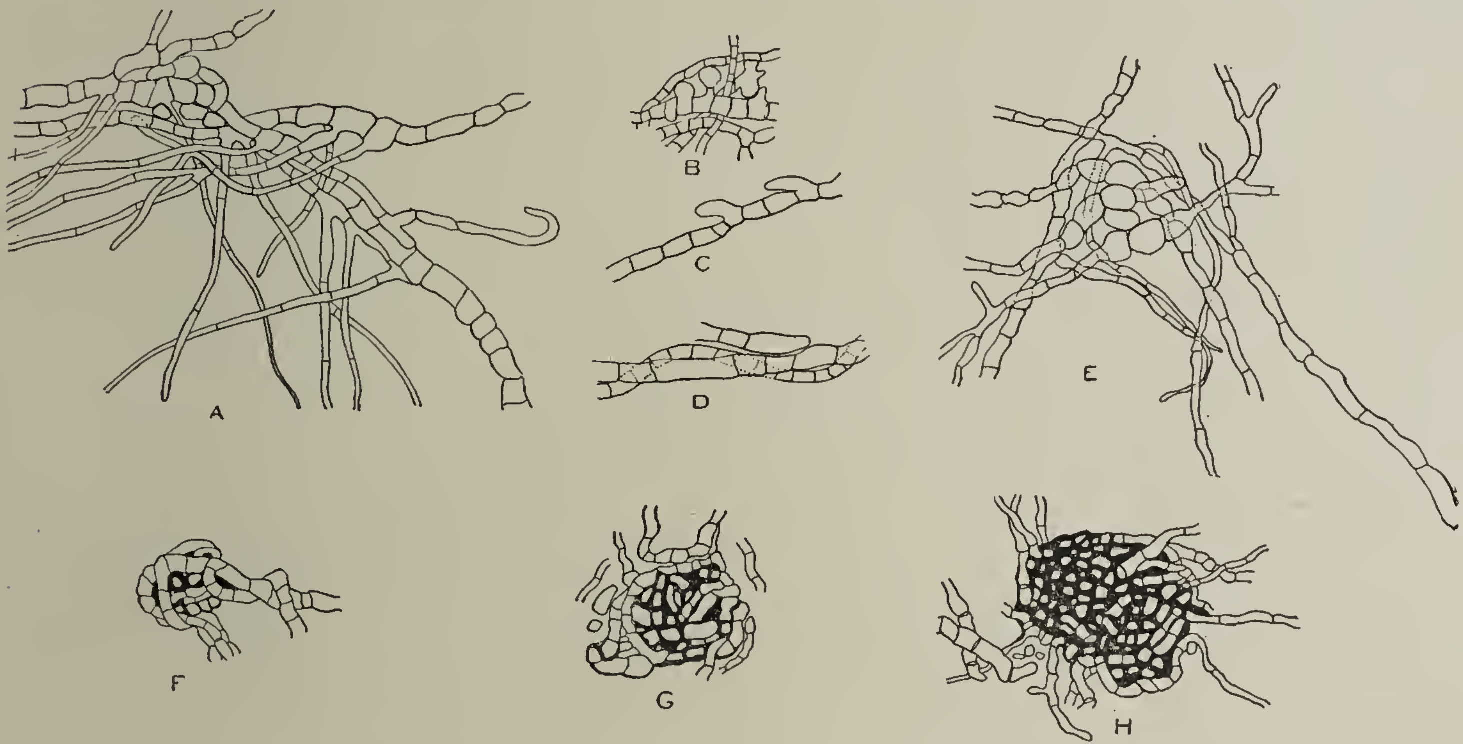


Fig. 23. DEVELOPMENTAL STAGES OF THE PYCNIDIUM

A, Early stage in pycnidial development. The hyphæ have become closely septate, are broadened, and are beginning to tangle. B, Early stage in the process, showing the origin of hyphæ which enter into the pycnidium. Some come from adjacent hyphæ, others arise from cells of the threads in the immediate tangle. C, Early stage. Branching of hypha, preliminary to coiling and twisting as in D and F. D, Early stage. Twisting of hyphæ about one another. E, Early stage, showing symphyogenetic and meristematic tendencies in pycnidial formation. F, G, H, More advanced stages in the process of pycnidial formation

The young pycnidium as it occurs in agar appears to be made up of a closely tangled mass of hyphæ. In section the young fruiting body is composed of pseudoparenchyma, the cells of which are closely packed and consequently somewhat angular (Fig. 23, H). As is noted by De Bary (1887:247), pycnidia may arise either as intercalary formations on hyphal branches by the swelling and division of cells, or by the union and interweaving of mycelial threads. The former process is termed meristogenetic and the latter symphyogenetic. A third possible method, not unknown among the fungi, is by a combination of these two processes.

Potebnia (1910:62), in a note on *Sphaeropsis pseudodiplodia* (Fckl.) G. Del., states that the pycnidia arise meristogenetically. The writer was for some time under the impression that this was the character of the process, but this opinion was based on observations of later stages rather than on the earliest steps in the development. The dense pseudoparenchyma of the maturer fruit bodies suggests meristematic divisions, but apparently the structure, for the most part, arises symphyogenetically (Fig. 23).

In agar cultures a group of threads may be observed to be directed toward a common point where the pycnidium is to be formed. Here the hyphæ are composed of cells from 6 to 7 μ broad, their length varying from 20 to 70 μ, always longer than broad. In the region where the pycnidium is to be developed, the cells become noticeably shorter by the laying down of new walls; the cells also increase in diameter by growth, and the hyphæ increase their numbers by branching (Fig. 23, A). This stage is observed with ease in petri-dish cultures.

The behavior of the threads in the formation of the pseudoparenchyma is varied and the process is somewhat indefinite. The mycelial branches that enter into the structure may arise from the short cells (Fig. 23, A), or they may grow in from adjacent hyphæ (Fig. 23, E). The interspaces found in the earlier stages are filled by the growing in of these branches and by a budding-like action of the hyphal cells bordering the space (Fig. 23, B).

Serial sections show that there is considerable coiling and gnarling of hyphæ. Threads may twist about one another for some distance in a rope-like fashion (Fig. 23, D). In some cases the threads are localized in their intertwining so that the resulting structure becomes a knot or ball of densely woven hyphæ (Fig. 23, F, G, H). The formation of such a structure necessitates that the hyphæ pass into many planes, and in cross sections the ends of many hyphæ present a pseudoparenchymatous appearance (Fig. 23, H).

In the intertwining process, hyphæ may conjugate in an H-shaped fashion. In some cases threads that are parallel probably fuse side by side, although the evidence for this is not complete.

The next important stage is the formation of the cavity. At first no differentiation of the closely tangled mass of threads is shown in the young pycnidium, but soon the preparation for the cavity is evident. Certain cells occupying the central region become more densely granular than the surrounding cells. This appears to be the beginning of the cavity. Later stages show the breaking down of these cells, and finally an oval or a globose cavity is formed. Baccarini (1890:69) states that these central cells transform by a mucilaginous process, and that the cavity is enlarged by the gelatinous center's absorbing water and exerting a pressure on the sporogenous layer. He emphasizes the importance of the central "tissue" and expresses the opinion that it has a special function, believing that it is destined to become sporogenous whereas the outer surrounding cortex only furnishes nourishment to these cells.

The formation of the ostiole is similar to the process exhibited by the development of the cavity. The cells break down, enlarging the passage, and finally the wall is definite and continuous with that of the spore cavity.

The spore-bearing area occupies almost all the space not included by the ostiole. The cells lining the cavity arch outward, and continued growth results in the formation of a stalk. The tip of the stalk swells, and ultimately a mature spore is cut off (Fig. 24). The further development of the pycnospores has been discussed.

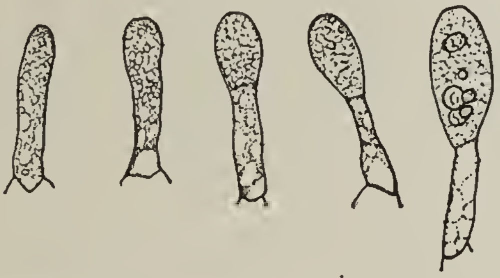


FIG. 24. PYCNOSPORE DEVELOPMENT

Stages in the formation of a pycnospore from a conidiophore

PYCNOSPORES. The morphology of the pycnospores has been more carefully studied than that of the pycnidia. In the same and in different pycnidia on the same and on different plants, wide variation with respect to size, color, shape, and septation have been observed (Fig. 25).

The average mature pycnospore measures about 12 by 25 μ, although the range in single or in different pycnidia on the same or on different hosts or host parts may be considerable. From the measurement of hundreds of pycnospores, it has been found that they range from 7 to 16.2 μ broad by from 16 to 36 μ long, while the averages from different hosts range from 9.5 to 13.3 μ by 19.8 to 27.8 μ. Spores on the apple show a slight variation on the different organs, as follows: on the fruit, 10.6 by 25 μ; on the twigs, 11.6 by 23.8 μ; on large limbs, 12.9 by 24.9 μ; on the foliage, 12.3 by 23.5 μ. Paddock (1899b:195, table 1) notes considerable variability with respect to size as the spores occur on different plants, but he says: "Yet the spores produced on apple fruits inoculated with cultures from either host, are of the same size and character; similarly, though not shown in the table, when pear trees are inoculated with cultures of Sphaeropsis taken from apple trees the resulting pycnidia and spores are of the average size of those found in nature on pear tree bark."

The mature pycnospores are brownish, varying from a very light to a dark ferruginous color. The color darkens with age, so that the very youngest mature spores are hyaline. The question of the maturity of these colorless spores has frequently arisen. The writer has germinated them, and is of the opinion that they should be regarded as physiologically mature. The hyaline color is replaced later by a yellowish green tinge, and finally a brown of varying density is assumed, the spore becoming very dark brown in the final condition of coloration, as noted above.

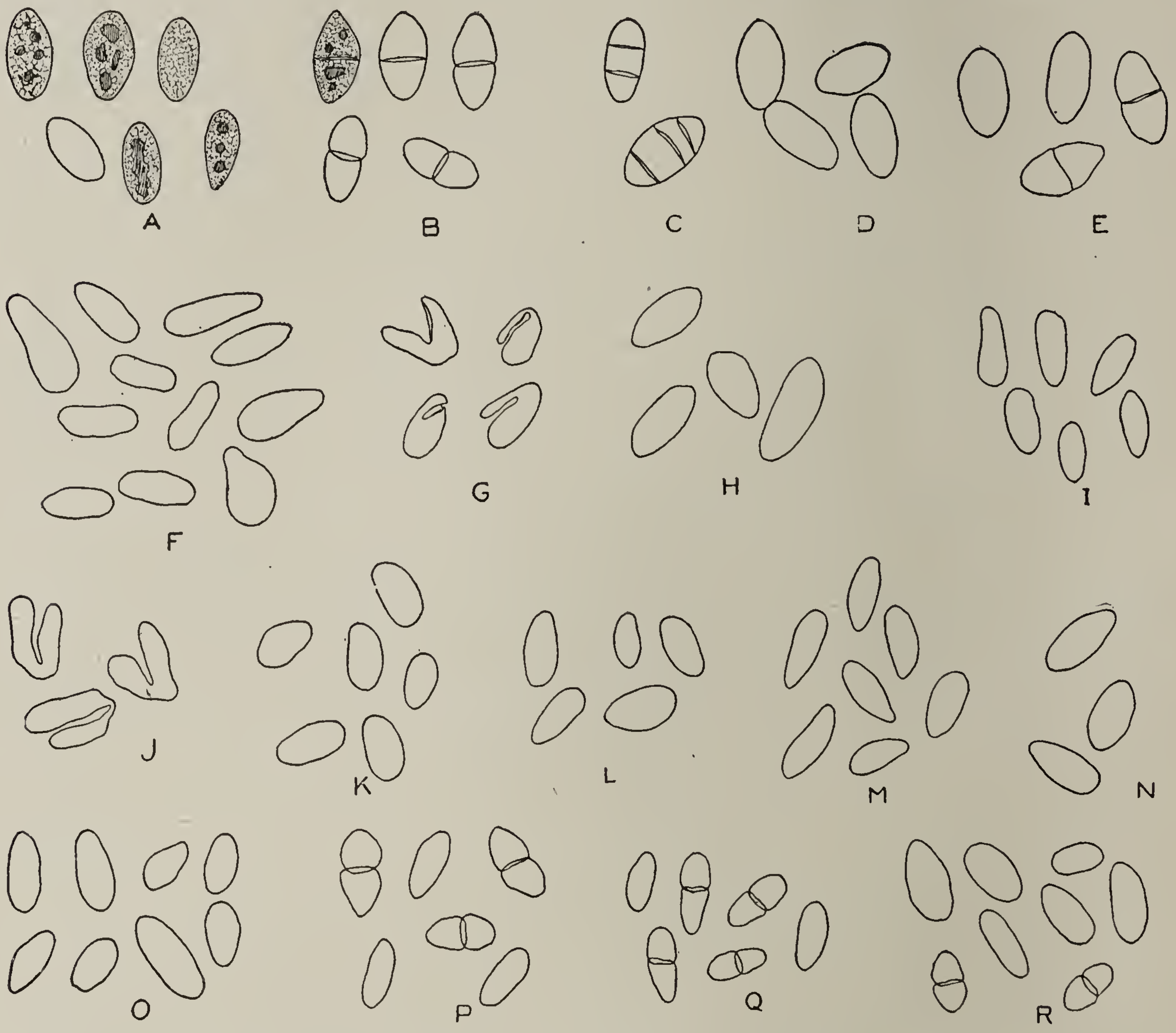


FIG. 25. VARIATIONS AND TYPES OF PYCNOSPORES OF PHYSALOSPORA CYDONIAE FROM VARIOUS HOSTS

A, Typical unicellular pycnospores; B, typical bicellular pycnospores; C, three- and four-celled pycnospores, not common; D, pycnospores from apple twig; E, pycnospores from apple limb; F, pycnospores from a single pycnidium, from apple twig; G, very old pycnospores which have burst; H, pycnospores from apple fruit; I, pycnospores from sumac; J, pycnospores from sumac showing peculiar fusion; K, pycnospores from sumac; L, pycnospores from crab; M, pycnospores from mulberry; N, pycnospores from rose fruits; O, pycnospores from bittersweet; P, pycnospores from rose of sharon; Q, pycnospores from witch-hazel; R, pycnospores from spicebush

The several shades of color may be represented by the spores of a single pycnidium, although the majority are uniform in this respect.

The typical pycnospore is ellipsoidal, frequently tapering slightly toward the basal end (Fig. 25, A). The shape also is a variable character, however. Pyriform spores may accompany ellipsoidal, globose, or somewhat elongated forms.

The question of septation of pycnospores is of importance because of the fact that it involves the systematic value of the character, or variation if it be so called, in separating the form-genera Sphaeropsis and Diplodia, and because of the physiological significance of its formation. In nature, three possible conditions exist with respect to the presence of one- and two-celled spores. A pycnidium may contain only one-celled spores (Fig. 25, A) or only two-celled forms (Fig. 25, B), or both kinds may be present (Fig. 25, E, P, Q, R). Occasionally three-celled and even four-celled pycnospores have been observed (Fig. 25, C). It is a striking feature in this regard that no strain has come under the writer's observation that will not produce two-celled spores. Just what factors induce cross-wall formation is a matter not well understood. Mature unicellular spores placed to germinate, whether germinating at once or not, will sometimes develop a septum. Again, spores that are found scattered about on the bark of the host plant show the bicellular condition. In very dark spores the cross-wall is not always readily visible and may be easily overlooked.

The writer made observations on several strains regarding this character. Spores were placed in a drop of water and set in a moist chamber for several hours. At the beginning and at the end of each experiment the spores were examined for septation. The strains when collected, with the exception of one (no. 64)[4] on mulberry (*Morus alba* L.), possessed one-celled spores only. After being placed to germinate, or in nature after they had oozed forth on the substratum, septa began to appear and the percentages were as follows: one-celled spores, from two to ninety-five per cent; two-celled spores, from five to ninety-eight per cent; three- and four-celled forms, rare. The average for all such observations shows that the percentage of one- and two-celled forms is about equal.

Cultural studies were made of an apple strain (no. 82) with reference to this and other morphological characters. A single ellipsoidal, brown, one-celled pycnospore, 10.8 by 21 μ in size, from a pycnidium in which all the spores were one-celled and typically like the one described, was isolated on March 3, 1913, and a pure culture was developed from it. Examination of the culture at intervals showed the development of hyaline, Macrophoma-like spores. At the end of twenty-four days these had become brownish, and, while the majority were ellipsoidal, averaging from 9 to 10 μ by 21 to 22 μ, a few were pyriform and measured 12.6 by 30.6 μ. At the end of fifty days an occasional spore was found with a cross-wall; after eighty days thirty per cent of the spores were two-celled, and on May 27 sixty per cent were bicellular.

From the same culture a second generation was originated by culturing a one-celled, ellipsoidal, brown spore, 11 by 22 μ in size. The following notes were taken: Within two weeks an occasional spore measured 7.5 by 21 μ, although the usual size was from 9 to 10.8 μ by 19.8 to 26.1 μ. After forty days several two-celled spores appeared. At the end of two months, fifty per cent of the spores were one-septate.

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[4] The specimens were numbered consecutively regardless of source, host, and other considerations.

A third generation was initiated by planting a spore from the second generation, of the same shape and measurement as the preceding. After one month twenty-five per cent of the pycnospores were of the Diplodia type.

Another series was studied, using a two-celled spore from a pycnidium in which both one-celled and two-celled forms were present. Within one generation a single spore, 10.8 by 21 μ in size, two-celled, brown, ellipsoidal, had developed offspring showing the usual color variations — that is, from hyaline to greenish, and finally brownish. After eighteen days some of the spores measured 12 by 28 μ, the average being 10.5 by 21 μ. Septation began to show after five weeks, and within eighty days sixty per cent of the spores examined were two-celled.

Apparently, from a single pycnidium in which the spores are of a given type there may develop in succeeding generations a wide variation in size, color, shape, and septation. In an early stage the Macrophoma type may appear in both size and color; later the Eu-Sphaeropsis type, one-celled, brown; and finally the Diplodia forms. The variable shapes that may be found in the generations succeeding a given type indicate that two-celled forms may be mere deviations in the life cycle. On the other hand, Brooks and DeMeritt (1912:184) report from New Hampshire a large-spored form which holds true to its morphological characteristics for several generations.

Markings on the wall of the pycnospores are reported by Griffon and Maublanc (1910:312). These authors claim to have discovered an undescribed character of the spores of this species, namely, a shagreened wall. This character is not reported elsewhere in literature, and has not been observed by the writer among the several strains studied, including Dr. Peck's type specimens of *Sphaeropsis Malorum* Peck.[5]

Long, slender bodies, measuring about 1.5 μ in diameter and often 50 μ in length, have been observed interspersed between the pycnospores of a strain from apple twigs. They are not of frequent occurrence in the experience of the writer.

MYCELIUM. The mycelium is composed of septate tubes, monopodially branched and comparatively broad — being on an average about 4 to 7 μ in diameter. In the young hyphæ cross-walls are rare, but in older branches the threads are often short and frequently with bulging lateral walls. Color is lacking in young aërial threads, but as age increases a greenish yellow, then bluish green, brown, and finally dark brown, hue is assumed. In mass the mycelium appears black. In cultures lacking potassium a violet tinge has been observed. The walls of the hyphæ are relatively thick, and sometimes a decided double contour of the membrane is visible. The appearance of the cell contents varies, apparently depending somewhat on age and nutrition. Young and well-nourished cells are densely granular, while older threads contain vacuoles and glycogen drops in abundance.

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[5] Following the Vienna Code published in 1906 (Wettstein, R. von, Wiesner, J., and Zahlbruckner, A., Verhandlungen des Internationalen Botanischen Kongresses in Wien, 1905, p. 200), this specific name should be capitalized.

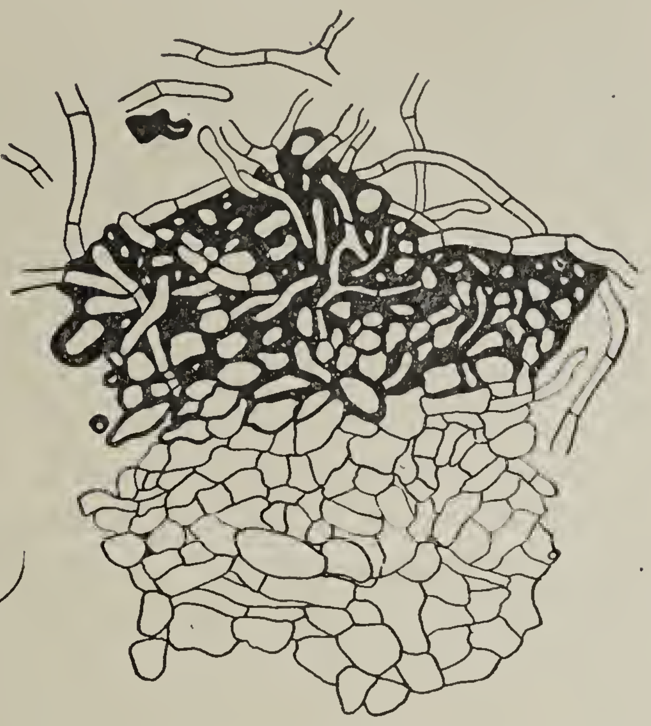

Fig. 26. PART OF CROSS SECTION OF SCLEROTIUM

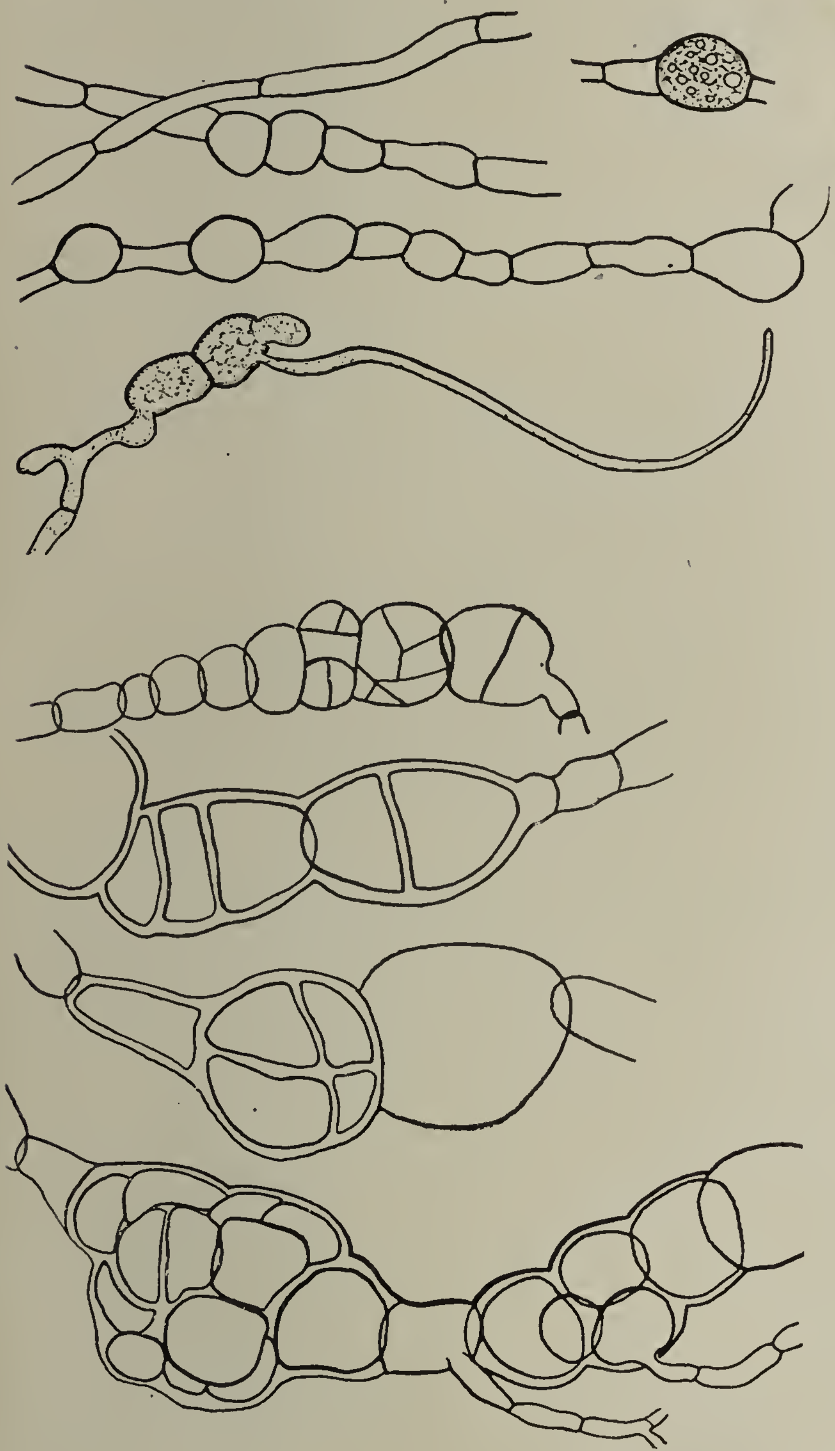

Fig. 27. CHLAMYDOSPORES OF PHYSALOSPORA CYDONIAE

Types of chlamydospores found in pure cultures

SCLEROTIA (Plate XIII, 3, and Fig. 26). Sclerotial bodies have been found in nutrient media of high sugar content and in oat agar cultures of ascospores from *Hamamelis virginiana*. Walker (1908:38) reports the development of sclerotium-like bodies resembling pycnidia on artificial media. They have also been observed by Baccarini (1890:67) just under the skin of the apple.

CHLAMYDOSPORES (Fig. 27). Chlamydospores have doubtfully been observed by the writer in host tissues. In a few cases a suggestion of such a body was found in apple bark. In old cultures on various artificial media, large, thick-walled, intercalary, brown, spore-like bodies are sometimes present in abundance. They were also obtained easily by transferring bits of mycelium to sterile water. They have been observed in agar cultures that have become contaminated by bacteria, being found more especially near the bacterial colonies. The most striking forms observed were on old agar cultures of the strain (no. 6) from *Rhus typhina* L. Similar bodies are described and figured by Hedges and Tenny (1912:16) in their studies on *Sphaeropsis tumefaciens*. These large bodies suggest young pycnidia, owing to the form and cellular structure. All gradations from thick-walled, colorless, greenish or brownish, granular, swollen cells, occurring singly or in chains, are very common in artificial culture. These bodies have been germinated by the writer, the germ tubes developing into hyphæ of the usual type (Fig. 27, near top).

MICROCONIDIA (Fig. 28). Microconidia, or secondary bud-like bodies, have been observed in culture after forty-eight hours. They develop as swellings near the tips of the growing hyphæ. They are globose or somewhat pyriform, measuring from 3.6 to 6.3 μ by 7 to 14.5 μ, averaging 4 by 9.5 μ.

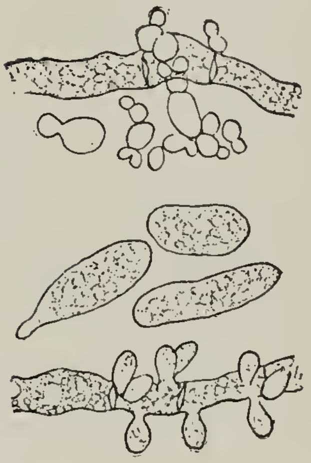
FIG. 28. MICROCONIDIA OF PHYSALOSPORA CYDONIAE

Showing microconidia developed on the mycelial threads. The three microconidia in the center are magnified 800 diameters

YEAST FORMS. Alwood (1898 b) records the discovery of a yeast form occurring in the laboratory cultures of the fungus, which on isolation and reinoculation of apple fruit produced its fruiting bodies. Such forms have never occurred in any of the writer's pure cultures.

The variations exhibited by this fungus do not represent unique phenomena among the fungi. Shear and Wood (1913:63) say of Glomerella: "No character, either morphological or physiological, seems to be well fixed." They find (page 64 of same reference) wide variability in the manner of conidial production; all intergradations between a hyphomycetous type and a distinct melanconiaceous type of structure occur in cultures. Setæ may be present in some cultures and absent in others, while paraphyses are regarded as of little taxonomic value. Duggar (1909:303), in speaking of the Alternaria-Macrosporium question, says: "The catenulate method of spore production has been reported only in artificial cultures in this case, and it is possible, furthermore, to obtain for various fungi in such cultures in general many variations from what would be considered the normal type of spore production upon the host." It is stated in the same place that cultures of such forms as Fusarium, Gloeosporium, and Cercospora yield variable characters in culture. Seaver (1908) points out the misleading and misused color characters in some of the Hypocreales. Stevens and Hall (1909 b) report considerable variation in certain forms under different environmental influences.

PHYSIOLOGY

METHODS OF ISOLATION. The chief methods used in isolating the organism were: the plating of spores in agar and the transfer of single germinating spores; transfer of single spores by the capillary tube method as described previously by the writer (1913:291–292); planting bits of diseased tissue in agar plates. The first two methods are advantageous in getting pure lines or races. The third method has practical advantages in its simplicity and the ease with which the culture is obtained.

CULTURAL CHARACTERS — GENERAL. The ability of this fungus to grow on the commonly used culture media is a noticeable physiological character. It is easily isolated, and its appearance in successive stages of development is generally the same in all the culture media employed. The colonies are at first cottony; after from two to five days the submerged threads are green or blue-green for about a week, after which the growth is dark or nearly black, but almost without exception the outer ends of the aërial threads maintain their original cottony appearance. After from seven to ten days pycnidia appear. The writer has always been able to develop pycnidia in culture, although Brooks and DeMeritt (1912:183) found considerable difficulty in getting cultures to sporulate. Often a distinct concentric zonation occurs in plate and tube cultures. The exudation in culture of drops of liquid has been observed frequently. This is described by Potebnia (1907), who regards it as an excretion product.

The general characters described above — except zonation, which is irregular in its occurrence — apply to the following media: several different agars, including potato, prune, apple, oat, bean, and nutrient; solid vegetable substances, such as potato cylinders, bean pods, apple twigs, and apple fruit cylinders; synthetic liquid media, such as Fraenkel and Voge's, Cohn's, Rankin's, and Uschinsky's solutions.

CULTURAL CHARACTERS — SPECIAL. The writer (1913:292–293) has previously reported differences in the growth of cultures from ascospores and pycnospores when planted in +10 nutrient agar. On the one hand pycnospores were developed within about one week from pycnospore plantings, whereas on the other hand no fruiting bodies had appeared after several weeks in cultures from ascospores, the growth remaining stunted. Cultures of ascospores and of pycnospores were similar on other media (Plate XIII, 1).

PROTOPLASMIC STREAMING. Protoplasmic streaming in the hyphæ has been studied by Potebnia (1907). He has found that movement begins with the germination of the pycnospore. The direction is first toward the tip, some granules moving more rapidly than others. On reaching the tip, those that have moved the faster direct their movement backward, in some cases forming groups. The streaming is not dependent either on evaporation through aërial parts or on the structure of the protoplasm, but is conditioned only by apical growth of the hyphæ and by inner processes. The slow movement is pulsative, and it is observed that increased temperature accelerates forward movement and cooling often induces backward flow. It is suggested that the streaming is similar to the slow movement observed by Van Tieghem in the hyphæ of the Mucorales..

PATHOGENICITY

The ability of the organism to produce the disease, particularly the leaf spot and canker forms, has been a matter of no little consideration. The difficulties that are met in attempting to infect various plants have brought out, not only some conflicting results, but also, what is more encouraging, some interesting problems with reference to the causal agent and the taxonomic relationship of the so-called species on the different host plants. The cross-infection of the several hosts, and the rôle of organisms associated with *Physalospora Cydoniae* in the production of the lesions, are points that have a practical and scientific bearing on the whole problem. The different forms of the disease are followed in the succeeding discussion.

BLACK ROT OF APPLE. The ability of the fungus to cause decay of fruits was established, after a fashion, in 1878 by Peck, who writes (1879:20) that "the disease is contagious, and may be communicated from one apple to another."

Von Thümen (1879)[6] regards the fungus, which he called *Diplodia Malorum* Fckl., as a saprophyte rather than a parasite, but believes that it is capable of attacking sound fruit and is able to cause notable injury in storage.

Arthur (1885) inoculated sound quinces by inserting beneath the skin a bit of diseased fruit tissue containing spores of the fungus (which he calls *Sphaeropsis Cydoniae* C. & E.). The inoculated fruits were placed under a bell jar. Arthur says: "The spores germinated, and the rotting progressed slowly, when, on the twenty-second day, the spot had reached an inch and a half in diameter, and the fruiting points had begun to appear."

Halsted (1892) states that the fungus grows interchangeably on apple, quince, and pear fruits. He reports having corroborated his laboratory experiments by field observations.

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[6] Original not seen by the writer; context taken from Baccarini (1890: 70).

Sturgis (1894) made inoculations both in the field and in the laboratory, confirming the work of Halsted (1892) and showing that when the skin was not broken previous to inoculation the fruits remained in a sound condition.

Paddock (1899 b: 185) produced black rot of apple artificially within a few hours by the use of the black-spored fungus, pycnidia appearing after sixteen days. Again, Paddock states (page 193 of same reference) that the fungus from pear, quince, and Japanese plum produces rot in apple, pear, and quince, if the skin is punctured and moisture is furnished.

More recent inoculation experiments are reported by Walker (1908), Morse (1909), Arnaud (1912), and others.

Two forms of Sphaeropsis were observed by Walker (1908), both of which were capable of producing black rot — the newer form, however, being a more vigorous rot producer. The morphological differences have been previously noted.

The writer made several inoculations (tables 1 and 2) on apples of different varieties, using different strains from bark and fruit. In all cases pure cultures of the fungus were used. In making wounds to serve as infection courts a flamed scalpel was employed. Material transferred from the culture consisted of mycelium and spores; this was inserted in the injury previously made, and the fruits were placed in sterile moist chambers. It is to be noted from table 1 that different strains vary in their ability to infect the same variety. Attention is called to a comparison of strains 1, 2, 3, and 4. All were used on Baldwin apples on the same date and under similar conditions, yet the results were different. Strains 1 and 3 showed slow decay, with no pycnidia after nineteen days. On the other hand, strains 2 and 4 caused rapid decay and abundant pycnidia in the same length of time.

As shown in table 1, nine different varieties were inoculated with the same culture, the results being variable with reference to decay, fruit body production, and the formation of concentric rings.

It has been commonly observed that older cultures produce the disease less readily than do younger cultures. The best results were obtained by the use of cultures not more than two months old.

LEAF SPOT OF APPLE. Various theories have been advanced to explain the cause of the leaf spot disease. In 1902 Stewart and Eustace (1902: 228) believed spray injury to be the responsible agency. They further suggest (page 232 of same reference) that drops of rain act as lenses and so concentrate the rays of the sun, overheating the tissues beneath. The belief is ultimately expressed by them that the large proportion of leaf spot in New York is due to spray injury and is not of fungous origin. Frost has been considered the causal factor by Stone and Smith (1903) in

TABLE I. RESULTS OF INOCULATIONS ON RIPE APPLE FRUIT IN THE LABORATORY, USING STRAINS OF THE FUNGUS FROM APPLE

Source and number of strain	Variety inoculated	Date of inoculation	Conditions provided	Number of fruits	Results
A–Twenty Ounce apple bark	Yellow Transparent	July 19, 1910	Fruits in sterile chamber. Tissue wounded. No moisture	4	100 per cent infection; pycnidia formed and fruit mummified by August 15
A–Twenty Ounce apple bark	Red Astrachan	July 19, 1910		2	100 per cent infection
Apple bark, not numbered	Oliver	January, 1911		1	100 per cent infection. Pycnidia after 16 days
Apple, not numbered	?	February 2, 1911		2	100 per cent infection. Slow decay on one fruit; other fruit well decayed in 8 days
A–Twenty Ounce apple bark	Red Astrachan	July 15, 1911		2	Pycnidia in 10 days
1–Apple twig	Baldwin	April 7, 1911		1	Slight infection after 19 days. Decay not typical. No pycnidia
2–Apple fruit	Baldwin	April 7, 1911		1	Pycnidia after 19 days. Decay rapid
3–Twenty Ounce apple bark	Baldwin	April 7, 1911		1	Decay slow. No pycnidia after 19 days
4–Russet apple bark	Baldwin	April 7, 1911		1	Pycnidia abundant after 19 days
A–Twenty Ounce apple bark	Yellow Newtown	January 12, 1911		2	Decay slow; lesion 1 cm. in diameter after 18 days. No pycnidia
A–Twenty Ounce apple bark	Ben Davis	January 12, 1911		2	Fruit about one-fourth decayed after 18 days. Pycnidia abundant
A–Twenty Ounce apple bark	Oliver	January 12, 1911		2	Fruit about one-fourth decayed after 18 days. Pycnidia abundant
A–Twenty Ounce apple bark	Cranberry Pippin	January 12, 1911		2	Lesion 6 cm. in diameter after 18 days. No pycnidia

A–Twenty Ounce apple bark	Northern Spy	January 12, 1911		2	Pycnidia after 16 days. Concentric rings apparent
A–Twenty Ounce apple bark	Rebel	January 12, 1911		2	Apple one-fourth rotten after 18 days. Pycnidia present. Concentric rings evident
A–Twenty Ounce apple bark	Rome Beauty	January 12, 1911		2	Apple one-fourth rotten after 18 days. Pycnidia present. Concentric rings evident

TABLE 2. RESULTS OF INOCULATIONS ON GREEN APPLE FRUIT IN THE LABORATORY

Source and number of strain	Variety inoculated	Date of inoculation	Conditions provided	Number of fruits	Results
A–Twenty Ounce bark.....	Yellow Transparent	July 14, 1910......	Wound, moisture	2	Decay slow after 5 days
A–Twenty Ounce bark.....	Yellow Transparent	July 19, 1910......	Wound, moisture	2	100 per cent infection. Fruits taken from tree, inoculated in laboratory
82–Apple bark...........	Twenty Ounce....	July 16, 1913......	Wound, moisture	4	Slight decay after 1 week. Whole fruit involved after 6 weeks. (Fruits about 5 cm. in diameter)
Check..................	Twenty Ounce....	July 16, 1913......	Wound, moisture	1	No infection
82–Apple bark...........	Twenty Ounce....	July 16, 1913......	Inoculation in wound made by codling moth	2	No decay. Wound dried out

Massachusetts. They write: "No organism was to be found as the cause of the injury, and from the sequence of events there could be no reasonable doubt that the frost was the destructive agency."

The fungus theory was probably first favored by Alwood (1892:59), who attributed brown spot to *Phyllosticta pirina*. This organism has been regarded as the causal agent by several other writers — Kinney (1895 b), Lamson (1899), and others. In 1895 Stewart (1896) found a new species of Phyllosticta, described as *Phyllosticta limitata*, responsible for an epiphytotic of leaf spot on Long Island. In 1907 the fungus *Phyllosticta pirina* Sacc. was transferred to the genus Coniothyrium by Sheldon (1907), and the organism is now designated as *Coniothyrium pirina* (Sacc.) Sheldon. Another species of Phyllosticta, *P. prunicola* Sacc., is listed by Tubeuf and Smith[7] as the cause of spotting of leaves of apple, plum, cherry, and apricot.

Alwood (1898 a) records, in addition to *P. pirina*, other fungi associated with the leaf spot, including *Hendersonia Mali* and *Sphaeropsis Malorum*. This is the earliest record that the writer has seen of the occurrence of the last-named fungus on leaves of apple, although Clinton (1902, and 1904:298) reports it as the common cause of leaf spot in Illinois and Connecticut in later years. The question of its relationship to the leaf spot disease, as well as that of other fungi, was subsequently studied by various pathologists.

Scott and Quaintance (1907) state that several different fungi, most prominent among which are *Phyllosticta* sp., *Hendersonia* sp., and *Sphaeropsis Malorum*, are connected with spots and may be responsible for the injury in some cases, yet they are not clear as to which are the real parasites. The following year the subject was investigated by Hartley, I. M. Lewis, and Scott and Rorer. Hartley (1908 b), in examining leaf spots of apple from the West Virginia Agricultural Experiment Station, found the following fungi: *Coryneum foliicolum*, *Coniothyrium pirina*, an undetermined species of the Tuberculariae, *Sphaeropsis Malorum*, *Monochaetia Mali*, *Pestalozzia breviseta*, *Phyllosticta limitata*, *Torula* (?) sp., *Macrosporium* sp., *Ascochyta* sp., *Phyllosticta* (?) *piriseda* (?), *Phoma Mali*, *Septoria piricola* (?), *Metasphaeria* sp., and an undetermined species of Leptostromaceae. He expresses the opinion that probably *Coryneum foliicolum* was formerly reported as a Hendersonia. The fact that the parasitism of *Coniothyrium pirina* was questioned by Stewart and Eustace (1902:228) led Hartley to investigate the pathogenicity of this species. He found that it would not affect healthy tissue, but that on the other hand, when wounds such as scalding, abrasion of epidermis, or punctures with hot and cold needles, were made in the tissue, the fungus in most cases grew and fruited. He concludes that *C. pirina* is a facultative, or wound, parasite only, and further that its ability to cause leaf spot in orchard trees to any extent remains to be demonstrated. In his opinion *Coryneum foliicolum* is less parasitic in the field than *Coniothyrium pirina*.

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[7] Tubeuf, K. F. von, and Smith, W. G. Diseases of plants induced by cryptogamic parasites, page 463. 1897.

I. M. Lewis (1908:367) writes as follows regarding the leaf spot situation in New Hampshire: "Believing that the exact relation of all the fungi associated with the spots had not been thoroughly tested, an investigation was begun during the past summer to determine, if possible, the cause of the disease as it occurs in this State, and means of control by various spray mixtures." He states further (page 368 of same reference) that on isolation it was found that the fungi predominating were *Coniothyrium pirina*, *Coryneum foliicolum*, *Sphaeropsis Malorum*, *Alternaria* sp., and one of the Tuberculariae. To Hartley's total list of fungi associated with apple leaf spots, C. E. Lewis (1912:51) adds *Cladosporium herbarum* (Pers.) Link and *Dematium pullulans* De Bary, while Brooks and DeMeritt (1912:182) report the isolation of a Fusarium. The first series of experiments made by I. M. Lewis (1908), on August 1 showed that many inoculations did not result in infections; from this Lewis reasons that "the period at which the leaf is naturally infected is earlier in the spring and summer." This view is upheld by C. E. Lewis (1912:55), who concludes that the older leaves are not so susceptible to infection as are young leaves; the work of Brooks and DeMeritt (1912:190), however, in which they conclude that infection may occur until the last of August, indicates that the question of biologic races was a factor overlooked by both I. M. Lewis and C. E. Lewis. As regards the general conclusions of I. M. Lewis's work it may be further quoted (1908):

> As a result of this season's inoculation experiments it is impossible to offer more than negative results as to the cause of the spots. I am of the opinion, however, that the fungus *Sphaeropsis malorum* which is known to cause canker of apple limbs and is an active parasite, will be found to be the primary cause of apple leaf spot. This supposition must, however, be supported by direct experiment before it can be definitely affirmed for the spots considered in this investigation.

The same year the results of further investigations by Scott and Rorer (1908) were published, in which a definite conclusion was reached. They state (page 49 of reference cited): "It was found that *Sphaeropsis malorum*, contrary to the general belief, is the cause of the disease." Regarding the associated species they conclude (page 52 of same reference):

> *Coniothyrium pirina* (Sacc.) Sheldon, although it occurs abundantly on apple leaf-spots, appears to have nothing to do with their formation.
>
> The several other fungi that were tested, such as *Hendersonia* sp., *Coryneum* sp., *Pestalozzia* sp., and *Alternaria* sp., proved to be non-parasitic in these experiments and probably occur on leaf spots only as saprophytes.

The work of Scott and Rorer is practically confirmed by C. E. Lewis (1909). After making several inoculation experiments the latter writes (1912:55), in agreement with Hartley (1908 b), as follows:

> The results of these inoculation experiments seem to indicate that Sphaeropsis is able to attack the leaves of orchard trees when they are inoculated early in the season under favorable conditions for growth. No spotting has been produced by any of the other fungi which have been tested although it has been found that they grow readily on dead spots which have been killed by other causes.

The investigations of I. M. Lewis began in 1908 and were continued by Brooks and DeMeritt in 1909. As Brooks and DeMeritt state (1912:183), the summer's work was not conclusive. Later cultural work revealed to them great variation in the nature of growth of different strains of the fungus, and also in the time required for spore production. It has been mentioned elsewhere (page 68) that these authors found morphological strains. This discovery led them to investigate the correlation between the morphological and biological variations of these forms. Their final conclusion (page 190 of reference cited) is: "Several strains of *Sphaeropsis Malorum* may be obtained, varying in general vigor and in power to produce diseased conditions. The large-spored form, with single-loculed, ostiolate pycnidia is largely responsible for the production of leaf spot."

The writer performed inoculation experiments in an attempt to produce apple leaf spot during the summers of 1910 to 1913 inclusive. In the experiments of 1910 the leaves of mature trees were inoculated in the following manner: Pycnidia were removed from pure culture and the spores liberated by crushing the fruiting bodies in a watch glass containing water. The contents of the watch glass were removed to an atomizer and the spores were sprayed on both surfaces of the leaves. In some cases the leaves were previously wounded with a needle, in others they were left uninjured. Data regarding the source of the fungus, the variety and age of the tree whose leaves were inoculated, the date of inoculation, the number of leaves inoculated, and the results, for 1910 to 1913, are given in table 3. It is to be noted that no moist chamber was provided in any of the experiments of 1910. In 1911 a series of inoculations made on May 27 resulted in infection where wounds and moisture were provided. The method of work here was the same as in 1910, except for the provision of a moist chamber. This consisted of a lamp chimney, into which the inoculated leaves were inserted and the ends of which were closed with damp cotton. The series of inoculations performed in July, 1910, and in August, 1911, should be compared. In neither case was a moist chamber used and the results were negative. In the experiments of 1912 and 1913 no spotting of the foliage was obtained by artificial inoculations. The writer has no explanation to offer. The explanation offered by Brooks

TABLE 3. RESULTS OF INOCULATIONS OF APPLE FOLIAGE, USING APPLE STRAINS OF PHYSALOSPORA CYDONIAE

Source and number of strain	Variety inoculated	Age of tree	Date of inoculation	Conditions provided	Number of leaves inoculated	Results
A–Twenty Ounce bark	Tompkins King, Rhode Island, Baldwin, Tolman, Swaar, Esopus, Yellow Transparent, Holland Pippin, Red Astrachan, Roxbury, Hubbardston	Mature, large trees	July 18, 1910	Various as regards wounds. Both surfaces inoculated. No moisture provided	130	Failed
A–Twenty Ounce bark	Banana....................	3 years...	May 27, 1911	Both surfaces inoculated. Some wounded, others not. Moisture provided for several hours in some cases	50	Where wound and moisture were provided, 100 per cent infection, with abundant pycnidia after 2 weeks. Other leaves, including checks, showed no signs of disease
A–Twenty Ounce bark	Oliver.....................	3 years...	August 2, 1911	Both surfaces inoculated. Some wounded by needle pricks, others not. No moisture	24	Failed
57–Apple bark........	Oliver.....................	3 years...	May 17, 1912	Both surfaces inoculated. Some wounded, others not. Moisture provided for several hours in some cases. Followed by drizzling rain	50	All failed
60–Apple bark........	Oliver.....................	3 years...	May 20, 1912	Same as preceding..........	110	All failed
69–Apple bark........	Oliver.....................	3 years...	May 29, 1912	Same as preceding..........	50	All failed
83–Esopus bark.......	Oliver.....................	3 years...	May 28, 1913	Same as preceding..........	50	All failed
90–Twenty Ounce bark	Oliver.....................	3 years...	May 28, 1913	Same as preceding..........	50	All failed

and DeMeritt (1912) for the leaf spot problem in New Hampshire is apparently not applicable under western New York conditions, since a variety of morphological forms was used in the inoculation work. The results obtained indicate that there is no correlation between morphological and biological characters with respect to pathogenicity.

CANKER OF APPLE. Waite (1898 a) was the first to attribute the canker to a fungous parasite; he suggested that *Schizophyllum commune* Fr. was the causal organism. Paddock (1899 b:183) found dark spores on the cankers, but supposed they belonged to some saprophytic form. However, he grew this organism, as well as *Schizophyllum commune*, on artificial media, and made pure culture inoculations in the following manner: A small opening was made in the bark by means of a sterilized knife, and a small quantity of material from bean stem cultures was inserted between the wood and the bark. The incision was covered with moist filter paper and kept moist for thirty-six hours. All the inoculations made in 1898 with the dark-spored fungus on apple trees were successful; other fungi failed and the wounds soon healed. Paddock's conclusions are summarized in the following words (page 184 of same reference): "These experiments showed conclusively that the dark-spored fungus can penetrate living apple-tree bark under certain conditions and produce a cankered condition of apple-tree limbs and also indicated that it may produce a diseased condition of pear-tree bark." Again he says (page 185 of same reference): "The result of over fifty inoculations made from cultures that were obtained from cankered apple tree limbs prove that the apple-tree canker of New York apple orchards is caused by a fungus of the genus Sphaeropsis." Over one thousand inoculations were made by him in 1899 (pages 200–201 of same reference) and only a very few gave negative results. He further asserts that the fungus causes canker of the quince if the material from pure culture is inserted under the bark, whereas under other conditions the experiments were not conclusive.

Paddock's work was continued (1900) for the purpose of confirming former results and to determine if possible the relationship between the species of Sphaeropsis that occur on various plants. He obtained cultures from apple fruit and apple bark, and inoculated the apple tree and other plants. The results were positive, thus further proving the pathogenicity of the organism, as well as establishing the identity of the fungus on fruit and bark. The conclusions reached by Paddock are essentially confirmed by C. E. Lewis (1909:188–189) and by McCready (1910).

The writer (1913:293) has summarized the results of earlier inoculation work as follows:

> During the past summer [1913] several inoculations have been made with cultures from the ascospores of the ascomycetous fungus. The apple, pear, quince, crab apple, and other plants were inoculated, in each case wounds being made to serve as infection

> courts. Three varieties of apples, namely Twenty Ounce, Baldwin, and Chenango Strawberry, were inoculated between May 20 and July 16, 1913. Eleven sets of experiments involving about seventy incisions were made, all of which gave positive infections, the checks remaining healthy.

The above quotation concerns the ascomycetous fungus from apple. A morphologically similar organism on *Hamamelis virginiana* did not produce infection, as is seen from the following statement (Hesler, 1913:293): "About twenty-five different inoculations were made [with the ascomycete from *H. virginiana*] on all the plants mentioned above but no infections occurred."

The writer has carried on inoculation experiments during the past four years, both in the greenhouse and in the field, the most of the work being directed toward the infection of bark tissues. The methods employed have already been described (page 79). The results discussed at this point concern only experiments in which apple strains of the fungus (*Physalospora Cydoniae* Arnaud [= *Sphaeropsis Malorum* Berk.]) were used on apple itself. The more important points in this regard are shown in table 4, indicating the source of the strain, the variety and age of the tree inoculated, the conditions under which inoculations were made, the number of inoculations, and the general results. The infection work done in the summers of 1910, 1911, and 1912 was not conclusive, but with the use of various strains more satisfactory results were obtained in the season of 1913.

It may be noted in table 4 that races of the fungus came from different varieties of apple, isolations being made from fruit, leaf, and bark. It was desired to determine if possible whether strains obviously living under saprophytic conditions, as those following winter injury and fire blight, were capable of inducing bark injury, and to determine the nature of the parasitism of certain other strains that appeared to be parasitic. The results on these points are conflicting and it seems that the strains are as variable in their biological relationships as in their morphological characters. A race may produce infection on slightly wounded bark after it has been living under saprophytic conditions, for example, following fire blight. Again, those strains which in nature appear to be acting parasitically may prove to be weak parasites, producing infection only under certain conditions.

Conflicting results along this line have raised the question of individual variation among varieties of the host plant as regards susceptibility or immunity. It is possible that individual hosts in the same or in different orchards may differ in this respect, but conclusive data are not at hand with which to answer the question.

The variable results of inoculations of the apple with the apple fungus indicate that the production of infection requires the proper strain, a

TABLE 4. RESULTS OF INOCULATIONS OF PHYSALOSPORA CYDONIAE ON APPLE BARK. ONLY APPLE STRAINS INVOLVED

Source and number of strain	Variety inoculated	Age of tree	Date of inoculation	Conditions provided	Number of incisions	Results
A–Twenty Ounce bark	Twenty Ounce	40 years	July 20, 1910	Various conditions as regards wounds and moisture	17	100 per cent infection where wounds and moisture were provided. Other inoculations failed
A–Twenty Ounce bark	?	Mature	June 22, 1911	Wound by barely breaking bark	2	Very slight infection
Check	?	Mature	June 22, 1911	Wound by barely breaking bark	2	No infection
A–Twenty Ounce bark	?	Mature	June 22, 1911	Deep wound to wood	4	Rapid spread
Check	?	Mature	June 22, 1911	Deep wound to wood	4	No infection
A–Twenty Ounce bark	?	Young shoot	June 22, 1911	Deep wound to wood	3	Infection good
Check	?	Young shoot	June 22, 1911	Deep wound to wood	3	No infection
A–Twenty Ounce bark	Baldwin	2 years	February 15, 1912	Wound	4	Failed (in greenhouse)
A–Twenty Ounce bark	Twenty Ounce	? (large)	May 17, 1912	Slit in bark to wood	2	Canker formed within 6 weeks
22–Decorticated apple wood	Twenty Ounce	? (large)	May 17, 1912	Slit in bark to wood	2	Slight discoloration after 6 weeks
38–Rhode Island twig following fire blight	Twenty Ounce	? (large)	May 17, 1912	Slit in bark to wood	2	Fair growth after 6 weeks
25–Chenango apple leaf	Twenty Ounce	? (large)	May 17, 1912	Slit in bark to wood	2	Slight growth, limited by a marginal crack after 6 weeks
57–Sutton apple following winter injury	Twenty Ounce	? (large)	May 17, 1912	Slit in bark to wood	2	Very slight growth after 6 weeks
59–Apple fruit	Twenty Ounce	? (large)	May 17, 1912	Slit in bark to wood	2	Failed
60–Twenty Ounce bark	Oliver	3 years	May 20, 1912	No wound	2	Failed. Weather cloudy and rainy
Check	Oliver	3 years	May 20, 1912	....	2	No infection
60–Twenty Ounce bark	Oliver	3 years	May 20, 1912	Wound; slit to wood by scalpel	2	Failed

TABLE 4 (*continued*)

Source and number of strain	Variety inoculated	Age of tree	Date of inoculation	Conditions provided	Number of incisions	Results
Check	Oliver	3 years	May 20, 1912	Wound; slit to wood by scalpel	2	No infection
60–Twenty Ounce bark	Oliver	3 years	May 20, 1912	Bruise, breaking bark	2	Failed
Check	Oliver	3 years	May 20, 1912	Bruise, breaking bark	2	No infection
60–Twenty Ounce bark	Oliver	3 years	May 20, 1912	Winterkilled, wound by scalpel	2	Failed
Check	Oliver	3 years	May 20, 1912	Winterkilled, wound by scalpel	2	No infection
60–Twenty Ounce bark	Oliver	3 years	May 20, 1912	Winterkilled, no wound	2	Failed
Check	Oliver	3 years	May 20, 1912	Winterkilled, no wound	2	No infection
38–Rhode Island twig following fire blight	Twenty Ounce	Mature	June 27, 1912	Wound to wood; moist cotton for several hours	2	Canker 1.5 cm. in diameter
60–Twenty Ounce bark	Twenty Ounce	Mature	June 27, 1912	Wound to wood; moist cotton for several hours	2	Failed
70–Walbridge apple tree	Twenty Ounce	Mature	June 27, 1912	Wound to wood; moist cotton for several hours	2	Very slight discoloration
A–Twenty Ounce bark	Twenty Ounce	Mature	July 1, 1912	Wound to wood; moist chamber for several days	2	Canker 3 cm. in diameter after 18 days. Secondary spreading in 1913
22–Decorticated apple wood	Twenty Ounce	Mature	July 1, 1912	Wound to wood; moist chamber for several days	2	Not very satisfactory in 1912. Spreading in May, 1913; pycnidia
25–Chenango apple leaf	Twenty Ounce	Mature	July 1, 1912	Wound to wood; moist chamber for several days	2	2 cm. in diameter. Slight spread in 1913
52–Apple leaf	Twenty Ounce	Mature	July 1, 1912	Wound to wood; moist chamber for several days	2	Slight discoloration. No spread in 1913
60–Twenty Ounce bark	Twenty Ounce	Mature	July 1, 1912	Wound to wood; moist chamber for several days	2	3.5 cm. in diameter 1912. No advance in 1913

61–Baldwin bark	Twenty Ounce	Mature	July 1, 1912	Wound to wood; moist chamber for several days	5	2.5 x 6.5 cm. each. A marginal crevice August 24, 1912. Spread in 1913: 1. No increase 2. No increase 3. Limb 5 cm. in diameter, half girdled in May and finally girdled in September. Pycnidia 4. No increase 5. 7 x 12.5 cm. Pycnidia
71–Culture from Chas. E. Brooks	Twenty Ounce	Mature	July 1, 1912	Wound to wood; moist chamber for several days	2	2.5 x 4 cm. by July 12. No advance in 1913
A–Twenty Ounce bark	Twenty Ounce	Mature	July 10, 1912	Wound to wood; moist chamber for several days	2	Failed
22–Decorticated apple wood	Twenty Ounce	Mature	July 10, 1912	Wound to wood; moist chamber for several days	2	1 cm. in diameter
25–Chenango apple leaf	Twenty Ounce	Mature	July 10, 1912	Wound to wood; moist chamber for several days	2	Failed
38–Rhode Island twig following fire blight	Twenty Ounce	Mature	July 10, 1912	Wound to wood; moist chamber for several days	2	1 x 1.7 cm.
52–Apple leaf	Twenty Ounce	Mature	July 10, 1912	Wound to wood; moist chamber for several days	2	Failed
60–Twenty Ounce bark	Twenty Ounce	Mature	July 10, 1912	Wound to wood; moist chamber for several days	2	1 cm. in diameter
61–Baldwin bark	Twenty Ounce	Mature	July 10, 1912	Wound to wood; moist chamber for several days	2	Twig 1 cm. in diameter, almost girdled
71–Culture from Chas. E. Brooks	Twenty Ounce	Mature	July 10, 1912	Wound to wood; moist chamber for several days	2	Slight infection
A–Twenty Ounce bark	Twenty Ounce	Mature	July 10, 1912	Wound to wood; moist chamber	2	Failed
71–Culture from Chas. E. Brooks	Twenty Ounce	Mature	July 10, 1912	Wound to wood; moist chamber	2	Failed
22–Decorticated apple wood	Twenty Ounce	Mature	July 22, 1912	Wound to wood; moist chamber	2	Failed
38–Rhode Island twig following fire blight	Twenty Ounce	Mature	July 22, 1912	Wound to wood; moist chamber	2	Very slight
52–Apple leaf	Twenty Ounce	Mature	July 22, 1912	Wound to wood; moist chamber	2	Failed

TABLE 4 (*continued*)

Source and number of strain	Variety inoculated	Age of tree	Date of inoculation	Conditions provided	Number of incisions	Results
60–Twenty Ounce bark	Twenty Ounce	Mature	July 22, 1912	Wound to wood; moist chamber	2	Slight
61–Baldwin bark	Twenty Ounce	Mature	July 22, 1912	Wound to wood; moist chamber	2	Slight
70–Walbridge apple tree	Twenty Ounce	Mature	July 22, 1912	Wound to wood; moist chamber	2	Slight
71–Culture from Chas. E. Brooks	Twenty Ounce	Mature	July 22, 1912	Wound to wood; moist chamber	2	2.5 cm. in diameter. Marginal crack after 30 days
25–Chenango apple leaf	Twenty Ounce	Mature	August 17, 1912	Wound to wood; moist chamber	2	Slight discoloration
68–Apple bark	Twenty Ounce	Mature	August 17, 1912	Wound to wood; moist chamber	2	Doubtful
25–Chenango apple leaf	Twenty Ounce	Mature	August 17, 1912	Wound to wood; moist chamber	2	Doubtful
68–Apple bark	Twenty Ounce	Mature	August 17, 1912	Wound to wood; moist chamber	2	Failed
82–Apple bark	Lady Blush	Mature	May 9, 1913	Wound by cut; no moisture	2	Failed
82–Apple bark	Lady Blush	Mature	May 9, 1913	Bark broken by bruise of shoe; no moisture	2	Failed
82–Apple bark	Lady Blush	Mature	May 9, 1913	Natural wound left by sucker	2	Failed
82–Apple bark	Lady Blush	Mature	May 9, 1913	Wound by cut; no moisture	2	Failed
82–Apple bark	Twenty Ounce	Mature	May 12, 1913	Wound to wood by cut	4	Failed
82–Apple bark	Twenty Ounce	Mature	May 12, 1913	Bruise by shoe	3	Failed
82–Apple bark	Twenty Ounce	Mature	May 20, 1913	Bruise by shoe on 8th day previous	5	100 per cent infection. Slowly spreading. Growth stopped by June 15
Check	Twenty Ounce	Mature	May 20, 1913	Bruise by shoe on 8th day previous	5	No infection

82–Apple bark	Twenty Ounce	Mature	May 20, 1913	Freshly bruised by shoe	2	Failed
82–Apple bark	Twenty Ounce	Mature	May 20, 1913	Bruise made 8 days previous	2	100 per cent infection. Slowly spreading. Growth ceased by June 15
82–Apple bark	Twenty Ounce	Mature	May 22, 1913	Wound by cut	6	50 per cent infection (mycelium used). Cankers 2 cm. in diameter after 2 months
82–Apple bark	Twenty Ounce	Mature	May 22, 1913	Wound by cut	1	Failed (spores used)
Check	Twenty Ounce	Mature	May 22, 1913	Wound by cut	1	No infection
82–Apple bark	Twenty Ounce	Mature	June 6, 1913	Wound by cut	5	100 per cent infection. Cankers about 2 x 3 cm. after 7 weeks
82–Apple bark	Twenty Ounce	Mature	June 18, 1913	Wound barely through epidermis	3	Cankers 1.5 cm. in diameter after 5 weeks
82–Apple bark	Twenty Ounce	Mature	June 18, 1913	Wound to wood	3	Cankers 2 cm. in diameter after 5 weeks
82–Apple bark	Baldwin twigs	Mature	July 16, 1913	Wound to wood	4	3 slight infections; 1 canker 1 cm. in diameter
Check	Baldwin twigs	Mature	July 16, 1913	Wound to wood	1	No infection
82–Apple bark	Chenango	Mature	July 16, 1913	Wound to wood	4	2 slight infections; 2 cankers 1 x 1.3 cm. after 1 week
82–Apple bark	Twenty Ounce	Mature	July 16, 1913	Wound to wood	9	7 cankers developed, averaging 1 cm. after 2 weeks
Check	Twenty Ounce	Mature	July 16, 1913	Wound to wood	3	No infection
82–Apple bark	Twenty Ounce	Mature	July 17, 1913	Wound to wood	5	5 cankers, averaging 1 cm. after 1 week
Check	Twenty Ounce	Mature	July 17, 1913	Wound to wood	1	No infection
82–Apple bark	Twenty Ounce	Mature	July 16, 1913	Wound by inserting red-hot scalpel	4	4 cankers, averaging 1.5 cm. after 1 week
Check	Twenty Ounce	Mature	July 16, 1913	Wound by inserting red-hot scalpel	1	No infection
82–Apple bark	Twenty Ounce	Mature	July 16, 1913	Wound by bruise	4	4 cankers averaging 1 x 1.5 cm. after 1 week
82–Apple bark	Baldwin	2 years	December 9, 1913	Wound by slit with scalpel	4	4 cankers after 1 week
Check	Baldwin	2 years	December 9, 1913	Wound by slit with scalpel	2	No infections

TABLE 4 (*concluded*)

Source and number of strain	Variety inoculated	Age of tree	Date of inoculation	Conditions provided	Number of incisions	Results
82–Apple bark	Baldwin	3 years	July 25, 1914	Wound by slit with scalpel	9	9 cankers, averaging about 1 x 3 cm. after 1 month
82–Apple bark	Northern Spy	3 years	July 30, 1914	Wound by slit with scalpel	9	All developed cankers, averaging 1 x 3 to 4 cm. after a month
82–Apple bark	Baldwin	3 years	July 30, 1914	Wound by slit with scalpel	1	Canker 1.4 x 4.8 cm. after 1 month
82–Apple bark	Baldwin	3 years	July 30, 1914	Wound by slit with scalpel	6	Cankers in each case, averaging 1 x 7 cm. after 1 month
82–Apple bark	Gilliflower	Mature	October 5, 1914	Wound by slit with scalpel	4	Failed

wound in which to initiate the relationship, and moisture until infection has occurred.

Associated species.— It has been noted elsewhere that the fungus *Schizophyllum commune* Fr. was suspected as being the cause of canker (Waite, 1898 a). This apprehension was undoubtedly based on association of the fruiting body of the organism with the lesions, as it is common to find this fungus fruiting on old cankered limbs. Paddock (1898 a) cultured this species and after inoculating apple limbs concluded that it was not the cause of the disease.

The rôle of associated species in the production of canker on apple is taken up somewhat at length by C. E. Lewis (1912). In Maine the fungi most frequently found on dying twigs and branches of apple are *Sphaeropsis Malorum*, *Myxosporium corticolum* Edgerton, *Coryneum foliicolum* Fckl., *Cytospora* sp., *Phoma Mali* Schulz & Sacc., and *Coniothyrium pirina* (Sacc.) Sheldon. Those often developing in plate cultures were: *Phyllosticta limitata* Peck, *Dematium pullulans* De Bary, *Cladosporium herbarum* (Pers.) Link, *Alternaria* sp., *Macrosporium* sp., *Fusarium* sp., *Epicoccum* sp., and *Glomerella cingulata* (Stonem.) Sp. & von Sch. To this list the writer adds *Septoria* sp., *Cephalothecium roseum* Cda., and *Aspergillus* sp. C. E. Lewis (1912:62) concludes "that Coryneum and Phoma can cause considerable injury to young trees and branches of orchard trees. Myxosporium and Cytospora do not attack healthy branches but it seems probable that they attack weakened branches." The writer's results with the various associated fungi may be summarized by the statement that none of the species enumerated above made growth on apple bark.

CROSS-INOCULATIONS AND HOST RELATIONSHIPS (Plates VIII, IX, XI, XIV). The identity of the various species of Sphaeropsis on the same and on different plants has been established in certain cases. That the species on the fruit of apple is the same as that on the bark was proved by Paddock (1899 b, 1900) several years ago, and confirmed by Potebnia (1907) more recently. A similar relationship for the fruit and foliage forms of the fungus has been proved by Morse (1909), while Scott and Rorer (1908) have demonstrated the identity of the organism on leaves and bark. The ability of these three forms to grow interchangeably on the several organs of the apple is no longer questioned, and the results of previous investigations are essentially confirmed by the writer in tables 1, 2, 3, and 4.

The pycnidial stage of *Physalospora Cydoniae* Arnaud (*Sphaeropsis Malorum* Berk.) has been collected by various investigators (Paddock, Arnaud, the writer, and others) on the following plants: apple (*Pyrus malus* L.), apricot (*Prunus armeniaca* L.), alder (*Alnus glutinosa* Gaertn.),

TABLE 5. RESULTS OF CROSS-INOCULATIONS WITH PURE CULTURES OF PHYSALOSPORA CYDONIAE FROM VARIOUS HOSTS*

Host from which fungus was obtained		Host inoculated																
		Apple (*Pyrus malus*)			Quince (*Cydonia vulgaris*)		Pear (*Pyrus communis*)	Crab (*Pyrus coronaria*)	Peach (*Prunus persica*)	Sweet cherry (*Prunus avium*)	Sumac (*Rhus typhina*)	Mulberry (*Morus alba*)	Maple (*Acer spicatum*)	Maple (*Acer pennsylvanicum*)	Ash (*Fraxinus americana*)	Elm (*Ulmus americana*)	Witch-hazel (*Hamamelis virginiana*)	Chestnut (*Castanea dentata*)
		Bark	Fruit	Foliage	Bark	Foliage	Bark	Bark	Bark	Bark	Bark	Bark	Bark	Bark	Bark	Bark	Bark	Bark
Apple (*Pyrus malus*)	Bark	259 +210 — 49	48 +45 — 3	512 + 58 —454	27 +10 —17	134 + 30 —104	40 +22 —18	9 +7 —2	14 + 2 —12	5 —5	2 +1 —1	9 —9	2 —2	9 —9	2 —2	6 —6	16 —16	10 +1 —9
	Fruit	1 +1	1 +1	10 +10	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Foliage	10 +4 —6	....	....	1 —1	....	1 —1	2 +2	2 —2	....	....	....	....	....	....	....	....	....
	Wood	4 +3 —1	....	....	....	....	....	2 +2	....	....	....	....	....	....	....	....	....	....
Quince (*Cydonia vulgaris*)	Bark	10 +5 —5	....	....	5 —5	....	....	2 +2	2 —2	....	2 +1 —1	2 —2	....	....	2 —2	4 —4	....	....
	Fruit	6 +4 —2	4 +4	10 —10	4 —4	....	7 +2 —5	2 —2	2 +2	....	....	4 —4	....	....	....	2 —2	....	....
	Foliage	6 +4 —2	....	....	....	....	2 +2	2 +2	....	....	....	....	....	....	....	....	....	....
Pear (*Pyrus communis*)	Bark	10 +6 —4	3 +3	25 —25	11 —11	....	6 +2 —4	4 —4	4 +2 —2	....	5 +2 —3	8 —8	....	....	4 +2 —2	8 —8	....	....
	Fruit	3 +3	....	....	2 —2	....	5 +5	2 —2	2 —2	....	....	....	....	....	....	....	....	....

Crab (*Pyrus coronaria*)	Bark	12 +10 — 2	1 —1	50 —50	5 —5	......	4 +4	4 +2 —2	4 +2 —2	......	2 —2	......	2 —2	......	2 —2	4 —4	......	......
Peach (*Prunus persica*)	Bark	6 +1 —5	8 +6 —2	30 —30	4 —4	......	......	......	12 +10 —2	......	......	......	......	......	......	2 —2	......	......
Sweet cherry (*Prunus avium*)	Bark	4 +4	......	......	4 —4	......	2 +2	2 +2	2 —2	5 —5	2 —2	2 —2	......	......	2 —2	2 —2	......	......
Sumac (*Rhus typhina*)	Bark	11 +3 —8	8 +7 —1	......	5 —5	......	2 +2	4 +4	4 +2 —2	......	2 —2	2 +1 —1	2 —2	......	2 —2	4 —4	......	......
Mulberry (*Morus alba*)	Bark	12 +6 —6	1 +1	......	5 —5	......	6 +3 —3	7 +2 —5	10 +4 —6	......	......	7 —7	2 —2	......	4 +2 —2	8 —8	......	......
Maple (*Acer spicatum*)	Bark	6 +4 —2	......	......	6 +1 —5	......	5 +4 —1	4 +2 —2	4 —4	......	3 +1 —2	2 —2	2 —2	......	2 —2	2 —2	......	......
Ash (*Fraxinus americana*)	Bark	......	......	......	2 —2	......	3 +1 —2	2 —2	2 +2	......	......	2 —2	2 —2	......	2 —2	2 —2	......	......
Witch-hazel (*Hamamelis virginiana*)	Bark	7 +2 —5	......	......	2 —2	......	4 +2 —2	4 —4	2 —2	......	2 —2	2 —2	2 —2	......	2 —2	2 —2	......	......
Elm (*Ulmus americana*)	Bark	3 +3	......	......	2 —2	......	2 +2	2 —2	2 —2	......	......	......	......	......	......	2 —2	......	......
Basswood (*Tilia americana*)	Bark	3 +2 —1	......	......	2 —2	......	2 +1 —1	2 —2	2 —2	......	......	......	......	......	......	......	......	......
Chestnut oak (*Quercus prinus*)	Bark	21 +21	......	......	......	......	......	......	......	......	......	......	......	3 —3	......	......	6 —6	10 +10

*The first number indicates the number of inoculations made. The numbers with a plus sign represent the number of infections; the minus sign indicates failure to infect.

ash (*Fraxinus americana* L.), basswood (*Tilia americana* L.), bittersweet (*Celastrus scandens* L.), box elder (*Acer negundo* L.), cherry (*Prunus avium* L., *P. pennsylvanica* L., *P. virginiana* L.), cherry laurel (*Prunus lauro-cerasus* L.), crab (*Pyrus coronaria* L.), currant (*Ribes* sp.), dogwood (*Cornus stolonifera* Michx., *C. sanguinea* L.), elder (*Sambucus canadensis* L.), elm (*Ulmus americana* L.), fig (*Ficus carica* L.), grape (*Vitis* sp.), hawthorn (*Crataegus oxyacantha* L.), hop hornbeam (*Ostrya virginica* [Mill.] K. Koch), lilac (*Syringa vulgaris* L.), maple (*Acer saccharinum* L.), mulberry (*Morus alba* L.), oak (*Quercus alba* L., *Q. prinus* L.), osage orange (*Maclura pomifera* [Raf.] Schneider), peach (*Prunus persica* [L.] Stokes), pear (*Pyrus communis* L.), persimmon (*Diospyros virginiana* L.), pine (*Pinus strobus* L.), plum (*Prunus domestica* L., *P. triflora* Roxbg.), quince (*Cydonia vulgaris* Pers.), rose (*Rosa canina* L., *Rosa* sp.), rose of sharon (*Hibiscus syriacus* L.), spicebush (*Benzoin aestivale* [L.] Nees), sumac (*Rhus typhina* L., *R. glabra* L.), sycamore (*Platanus orientalis* L.), witch-hazel (*Hamamelis virginiana* L.). Where fresh material was available the writer cultured the fungus from all these plants except three — dogwood, lilac, and rose of sharon, which have just been collected — and these cultures were used in all cross-inoculation experiments. The source of the cultures used, the plants inoculated, and the results, are shown in table 5. The methods used were similar to those described in connection with the inoculation experiments on apple fruit (page 79). In some of the earlier experiments a moist chamber was used consisting of a petri-dish lid, the inner margin of which was lined with damp cotton. Later the glass lid was eliminated and a cotton cap, made by rolling a strip of cotton about the finger, was employed. Moisture was provided at the time of inoculation and was added daily for several (usually from three to seven) days subsequently.

The results of cross-inoculations were not conclusive, particularly in cases in which the fungus failed to develop. Failure to produce infection may be accounted for in two ways: either the fungus was not parasitic on the plant inoculated, or conditions favorable for infection were lacking. In many cases further trials are desirable.

In nature the fungus rarely shows a parasitic tendency on wild plants — with the exception of *Quercus prinus* (see Rankin, 1914) — but it is generally found developing on dead and fallen twigs; cankers have not been observed which could with certainty be attributed to this organism. On cultivated plants it commonly shows the same habits as it does on wild plants, or it may develop in healthy tissues, resulting in the formation of a canker. Here, then, on the cultivated plants are found both saprophytic and parasitic tendencies. This phenomenon is in accordance with the commonly accepted theory that parasitism originated from saprophytism. This is what is to be expected; and the theory is further supported by inoculation data which show that the strains from wild plants may be induced to infect cultivated plants. The reverse process — that is, the infection of wild plants with strains from either cultivated or wild forms — has been almost wholly unsuccessful in the writer's experience. This in the main confirms the work of Paddock (1899 b, 1900).

On certain wild plants there is found a saprophytic race which, when carried to cultivated forms such as the apple or the pear, acts as a wound parasite. On cultivated plants the fungus follows fire blight and winter injury, and hence is a saprophyte, but the latter strains are not necessarily obligate saprophytes since they have been induced to cause canker by artificial inoculation. This is shown by strains 22, 38, 57, and 70 in table 4. It does not appear, therefore, that the fungus can be segregated easily into physiological groups, since varying degrees of parasitism are exhibited by a given race.

From the experiments described and tabulated it is clear that there is considerable variation in the virulence of races, but just how long a given parasitic strain will retain this mode of life is a difficult question to answer. The ability of the organism to act as a wound parasite, and to adapt itself naturally to the saprophytic mode, makes it a serious pest from the standpoint of control. Its ability to remain saprophytic indefinitely until the host is injured in some way only increases the difficulty in alleviating the disease.

NAMES AND SYNONYMY

The work that has been done on cross-inoculations and on the morphology of Sphaeropsis from several different plants makes it apparent that there is one large polymorphic species. It is true that many inoculations failed, and that two given races may differ widely in their morphology; but there is considerable evidence that these characters are variable and are not important in taxonomic considerations.

The several forms as they have been described from time to time have been given a specific name, usually one for every host plant. This procedure has resulted in the accumulation of a large number of specific names which could now be disposed of only by the examination of type material of each so-called species. Several generic names have become involved in the synonymy of the fungus, due to the indefinite limitations and wide variations, and consequent overlapping, of certain form-genera. Saccardo (1884 a) believed *Sphaeropsis Malorum* Berk. to be a Phoma, since it was originally described by Berkeley (1836) as having yellowish green spores. It is now known that the young spores have this color characteristically, and furthermore Dr. C. L. Shear, who has seen Berkeley's type, has stated (in conversation with Dr. Donald Reddick, of Cornell University) that the organism is unquestionably identical with *Sphaeropsis Malorum* as now recognized. Subsequent to Saccardo's use of the name *Phoma*, this genus was divided into Phoma and Macrophoma — the former genus containing species with spores less than 15 μ long, the latter containing species with spores more than 15 μ long. Thus *Phoma Malorum* (Berk.) Sacc. was renamed by Berlese and Voglino (1886) as *Macrophoma Malorum* (Berk.) Berl. & Vogl.

It appears that certain species of Sphaeropsis have been confused with those of Diplodia. The two genera are separated on the basis of one-celled spores in the former and two-celled spores in the latter. But both genera fail in their chief distinction, so that mycologists have been misled on this point. Fückel (1869:393) used the name *Diplodia pseudodiplodia* Fckl. in describing the fungus on branches of apple; elsewhere (page 395 of same reference) he used *Diplodia Malorum* Fckl.

It has been noted previously that the pycnidium sometimes approaches and even reaches the condition characteristic of the form-genus Botryodiplodia. It becomes evident that the names of certain species of this genus may stand only as synonyms of *Physalospora Cydoniae* Arnaud.

The origin of several of these synonyms has been discussed in an earlier paper by the writer (1912), to which the reader is referred. At that time it seemed desirable to attempt the selection of the name that should, according to the rules of priority, be applied to the pycnidial stage. Recently, however, the perfect stage of the fungus has been found, and thus the selection of a specific name from the pycnidial forms is of minor importance. The generic name now becomes Physalospora, and the writer has chosen *Cydoniae* as the specific name. The following statements bearing on this question are quoted from another paper by the writer (1913:295):

> The problem of selecting a specific name is somewhat perplexing. The organism with which the writer is dealing strongly resembles *P. Cydoniae* Arnaud but we have not seen his type material and there remains the question of whether his fungus has not been previously described. In this connection a few species which suggest this possibility may be noted: *P. entaxia* E. & E., *P. festucae* (Lib.) Sacc. and *P. nigropunctata* Romell, the last on limbs of *Pyrus malus* according to Saccardo. Until further data are at hand the writer is inclined to accept tentatively the name *Physalospora Cydoniae* Arnaud.

Soon after the above-mentioned paper appeared in print, the writer received from Arnaud a glycerin-jelly mount of his type material. It is clear that morphologically the organism is identical with the one described by the writer (1913) under the same name. But the question of the specific name is still unsettled, for it is not improbable, as stated above, that the organism has been previously described under some other specific name. This problem, as in the case of the several pycnidial forms, would involve the study of type material, which as yet has not been available to the writer. Under the circumstances Arnaud's specific name will be retained tentatively by the writer. The following is a partial list of species which are concerned in the synonymy of the fungus; citations to literature are also given:

Physalospora Cydoniae Arnaud. École Nat. d'Agr. Montpellier. Ann. **12**:7. 1912.

Sphaeria sumachi Schw. Amer. Phil. Soc. Trans. n. s. **4**:205. 1834.
Sphaeria rhuina Schw. Amer. Phil. Soc. Trans. n. s. **4**:218. 1834.
Sphaeria pomorum Schw. Amer. Phil. Soc. Trans. n. s. **4**:219. 1834.
Sphaeria Malorum Berk. English Flora **5**:257–258. 1836.
Diplodia pseudodiplodia Fckl. Symbolae Mycologicae, p. 393. 1869.
Diplodia Malorum Fckl. Symbolae Mycologicae, p. 395. 1869.
Sphaeropsis Cydoniae C. & E. Grevillea **6**:84. 1878.
Sphaeropsis Malorum Peck. Sylloge Fungorum **3**:294. 1884.

Several years ago Ellis (1880) studied the variability of *Botryosphaeria fuliginosa* (M. & N.) E. & E. [= *Sphaeria Quercuum* Schw.], and came to the conclusion that this species really included at least eighteen so-called species. Among these may be noted, using Ellis's nomenclature, *Sphaeria entaxia* C. & E. [= *Physalospora entaxia* Sacc.], *S. viscosa* C. & E. [= *P. viscosa* Sacc.], *S. erratica* C. & E. [= *P. erratica* Sacc.], *Botryosphaeria pustulata* Sacc., and others. Ellis found wide variation with respect to stromatic formation. Sometimes the perithecia were scattered and distinct, and again they were confluent and united in a stroma. Considerable range with respect to the ostiolum is also noted by Ellis (1880). But, as stated by Ellis and Everhart (1892:547), certain forms of *Botryosphaeria fuliginosa*—those lacking a stroma—are removed to the genus Physalospora. It may be that under certain conditions *P. Cydoniae* develops a stroma, but such a tendency has not been observed; for this reason the generic name Physalospora is selected.

LIFE HISTORY STUDIES

The mature morphological structures of the fungus have been described, so that the following paragraphs concern only the successive stages in its development: where and in what condition the organism hibernates, the manner in which it is disseminated, its entrance and effects on the plants attacked, and the development of certain of its fruiting bodies.

SOURCE OF THE INOCULUM. The fungus passes the winter as mycelium in the tissues of the host and as pycnospores in pycnidia. If a canker is examined in the spring when growth is resumed by the host plant, the margin of the old lesion may show discoloration. The writer has frequently planted bits of the bark from the edge of a canker in agar plates, pure cultures resulting. This is evidence of the resumption of growth of the mycelium in the old lesion. It is stated by Caesar (1909) that as a rule the fungus does not die out but continues to extend in every direction year after year, finally girdling the limb. In this connection Paddock (1899 b: 189) writes as follows: "In some instances the mycelium apparently lives over winter and continues its growth the following spring. The formation of the largest cankers can scarcely be explained in any other way." He adds, however, that "in all of the inoculations made in the spring of 1898, in only one instance did the resulting canker enlarge any during the present season."

The writer's experience in this regard is somewhat similar, although more cankers have enlarged the second year than is intimated by Paddock. On this point there appears to be a difference in orchards. In one orchard the author counted forty cankers on three trees on May 20, 1912. All were formed at least one year previously, but only one showed advancement at the margin on this date. In other orchards a majority of the cankers were enlarging. The vitality of the trees does not seem to explain the difference displayed, since this quality appeared similar in the two cases mentioned. The trees in the two orchards were of the same variety (Twenty Ounce); here the question of physiological races may throw light on the subject.

It has been suggested that the mycelium may winter over in mummified fruit, and that in cases in which the fruit hangs on the tree the hyphæ may pass into the branch supporting it (Anonymous reference, 1899 c, page 126). The latter condition has not been observed by the writer. In some cases the mycelium hibernates in the mummified fruit, but the passage of the hyphæ down into the branch and the resulting development of a canker is questionable.

The growth of the mycelium at the edge of a lesion, as described above, does not account for new and isolated cankers. The phenomenon results nevertheless, indirectly, in a source of inoculum, in that fruit bodies may develop on the newly infected margin and so furnish spores which may cause other infections directly. The young cankers originate by the agency of the spores of the fungus.

It is a common thing to find, in the winter and spring, pycnidia bearing mature spores on mummified fruits. These fruiting bodies may be observed also on cankers and on fallen twigs, bark, and leaves. In western New York cankers and dead twigs are the most important sources of the inoculum.

The hibernation of pycnospores on the various organs of the tree is reported by a number of investigators: on the bark, fallen twigs, and cankers, by Paddock (1899 b: 189), by Brooks and DeMeritt (1912: 189), and by Scott and Rorer (1908: 52); on fallen leaves by Reed and Cooley (1911); on the fruit, as mummies hanging on the tree or fallen, by Scott and Rorer (1908:52) and by Brooks (1909). Other writers have confirmed all these observations. These spores in winter have been placed in room temperature, and were subsequently found to be capable of germination in tap water. There is evidence that pycnospores may also winter over scattered about on the bark; they have been found in early spring before the pycnidia have entered their period of spore discharge.

The rôle of the ascosporic stage in hibernation is not certain. As previously indicated, the perithecia are rare on *Pyrus malus* in New York, and it would seem, therefore, that the ascospores from this source are of relatively little importance in initiating infections. Whether this stage is common on other plants in this State, and important as a source of inoculum, are matters remaining to be investigated.

METHOD OF SPORE DISCHARGE. The manner in which the pycnospores escape from the pycnidium has not been fully described, so far as the writer knows. Berkeley (1836) makes mention of the process as follows: "When dry the ostiolum is frequently crowned with a short minute tendril oozing out from the perithecium." Halsted (1892) writes: "The ripe spores . . . . form long, slender coils as they are pushed out of the small hole in the skin." Similar descriptions of the process are given by Clinton (1902) and by Evans (1910).

If a bit of bark or of fruit bearing pycnidia is placed under moist conditions, in a few hours dark masses of spores in the form of a coil may be seen (Plate XIII, 4). In one experiment the following notes were taken: "Twigs of an apple strain (no. 82) bearing mature brown pycnospores were placed in a moist chamber on May 20, 1913, at 3 p. m. By noon on May 23 the dark masses could be seen with the naked eye. These masses measure about 200 to 250 μ by 400 to 450 μ." At this time it was observed that the masses stood out from the surface of the bark nearly five millimeters. They were very easily removed by a needle and examined under the microscope. It was observed that on the side of the mass nearest the bark several spores had germinated, and the resulting hyphæ had raised the mass away from the surface of the bark. A drop of water was added to one mass, which behaved as follows: In a few seconds the mass began to segregate, and single spores or groups of a few moved very quickly, with a darting motion, from the mass. They were at first thrown through the drop of water as far as 85 μ and they then moved slowly away. After forty-five minutes the spores had scattered in all directions, from 1500 to 2800 μ from the original point of departure. The coil in some cases contained about 1500 mature spores and in some experiments proved to be at least one millimeter in length. It has been estimated by the writer that there may be as many as 150 pycnidia on a square centimeter of the surface of an apple fruit; this would furnish approximately 225,000 spores for the given unit area, or 1,406,250 spores per square inch of apple surface.

As stated in the notes quoted above, the spore coils were found on the bark three days after moisture was supplied. But this does not mean that all this time was involved in the process of escape. The pycnidia were found to be closed at first and considerable time must have been consumed in their opening. In other experiments as long a period as five days was necessary to effect the opening in some cases. The time that actually intervenes between admission of moisture to the spore mass within the pycnidium and the coiling of the spores is negligible. Pycnidia have been removed from dry bark in the summer, placed on dry slides, and observed with the microscope. If a drop of water is then applied, the spores will ooze out immediately provided the ostiole is open. Their fate after coiling seems to depend on the amount of moisture present. If a beating rain is falling, undoubtedly the spores are carried by the spattering drops toward the ground and perchance lodge on the foliage or on the branches. In case of a dew, unquestionably the coil behaves as described above; that is, some of the spores on the lower side of the mass germinate, the resulting weft of germ tubes raising the spores from the bark, when they may be lifted by the wind. Again, if the mass encounters a drop of water the gelatinous material quickly expands and the spores are scattered throughout the drop. It is conceivable that the drop may be carried by the wind for a short distance at least.

TIME OF SPORE DISCHARGE. The time of the year when spores are disseminated may be approximated by noting the date of the first appearance of the diseased spots, and by keeping careful watch of the behavior of the pycnidia in the field. It is believed by I. M. Lewis (1908) that the period when foliage is naturally infected is early in the spring and summer. The same opinion is expressed by Brooks (1909), who states that the indications are that leaf infection ceases in June. Later, however, Brooks and DeMeritt (1912:189) attach little value to this statement, expressing the opinion that the nature of the fungus was a factor overlooked by previous investigators and that weather conditions may play a part in determination of the time of infection.

Paddock (1899 b:189) states that many spores remain in pycnidia until the following spring, when they are disseminated. Wolf (1910) has made a study of the prevalence of fungus spores in orchards by exposing agar plates, and his conclusions are expressed as follows (page 202 of reference cited): "At no time during the period in which exposures were made (September to May, inclusive) were viable spores of *Sphaeropsis malorum* present in the atmosphere of the orchard." McCready (1910) reports mature spores as being disseminated from cankers as early as the first week in April, and states that at the same time a large number of spores were found in the orchard on rotten apples. In Virginia, at Blacksburg, Reed and Cooley (1911) found spores being discharged from pycnidia on leaves on June 25, 1910. Whether spores are liberated at an earlier date these authors do not state, but it is probable that such is the case.

From observations made by the writer it seems that the date of first discharge in the spring varies with the season. Apparently the ostiole does not open at a temperature below 60° F. (15.5° C.) or in the absence of moisture, and a period of humidity of several hours duration is necessary. The dates for spore discharge observed at Byron, New York, are May 16, 1912, and May 12 and 23, 1913. In 1911 spores were found coiling on July 17, but the process must have occurred earlier. That they continue to be liberated throughout the summer is shown by the appearance of new infections on foliage from May until September 20, 1913. In 1911 several young spots were found on bark in the middle of August. Ripe and green fruit infections also show that spores are disseminated in August and September.

AGENTS OF DISSEMINATION. It is clear that the behavior of the pycnospores on being discharged places them at the disposal of wind, rain, and possibly insects, depending largely on the conditions of moisture. Halsted (1892) states that "the germs pass . . . . through the air or by means of the various insects that visit the fruits, especially those with broken surfaces due to partial decay." A similar opinion is expressed by Sturgis (1894). Lamson (1902:76) states that the spores are easily floated in slight currents of air, while Bethune (1909:29) and McCready (1910) attribute dissemination to the wind.

The writer has observed numerous cases of the disease in isolated situations. In some orchards there was abundant leaf spot but no cankers were on the trees. Here the wind probably acted as the agent, carrying the spores from plants outside the orchard. That the rain washes the spores to the foliage is shown by the cone-shaped area of infections beneath cankers and diseased fruits.

Insects are no doubt agents in the dissemination of the organism. The gelatinous nature of the spores renders them sticky and they may adhere to the feet of insects. In June, 1913, the writer found spores on the feet of the rosy apple aphis (*Aphis sorbi* Kaltenbach), but it is his opinion that insects are of little importance in carrying the spores. Their rôle in making openings in the fruit and bark is probably much more important.

INFECTION COURTS. The fungus shows little preference for any particular type of injury as a means of entrance. It is not able to penetrate healthy tissue of the bark and fruit, but follows other fungi such as *Glomerella cingulata* (Stonem.) S. and vS. on fruit, as noted by Alwood

(1902:257). Other points of entrance to fruit, as listed by Burrill and Blair (1901), are insect punctures, mechanical injuries, and the blossom end of the apple. These authors state also that the fungus seems to start without the aid of a wound. The writer has noted many cases in which young lesions on the apple surrounded an opening made by the codling moth (*Carpocapsa pomonella* L.). Delacroix (1903 a:140) is disposed to believe that in some cases certain insects are able to rupture the bark, especially that of young branches. He observed an abundance of *Epidiaspis piricola* (Del Guer.) Ckl. on infected areas, and is of the opinion that these insects are concerned here. Güssow (1911) states that "apples are infected through some injury (wasps, curculio, hail, etc., etc.)." Arnaud (1912) believes that there is some connection between the entrance of the fungus, and a beetle.

Observations show also that various mechanical injuries commonly serve as points of entrance for the fungus. Such injuries as limb and hail bruises may act in this capacity. Faurot (1912) states that rot occurs largely on fruits the skin of which was previously broken by spray injury and growth cracks.

Whether the healthy epidermis of the fruit is penetrated, as suggested by Burrill and Blair (1901), is open to question. The writer has never been able to infect unbroken tissues of the apple fruit. On the foliage, artificial inoculations by various investigators — Scott and Rorer (1908), Brooks and DeMeritt (1912), and others — show that the fungus can penetrate healthy leaf tissues. The author, however, has never been successful in producing leaf spot without first wounding the tissue. Infections in the bark apparently occur only through some sort of wound. Such injuries may be caused by growth cracks, as noted by Caesar (1909); by ladders and boots, in pruning and picking; by barking by the machinery, in cultivation; by props not carefully wrapped; by hail; by openings left by the careless removal of water sprouts; and in other ways. Of fifteen young cankers observed by the writer on a single tree, ten had their origin in openings left by the removal of suckers. The writer has observed cases in which the fungus had followed the rust fungus, *Gymnosporangium Juniperi-virginianae* Schw., on apple twigs. Scott and Rorer (1909:11) suggest that it may follow *Phyllosticta solitaria* E. & E. on apple buds. The writer has frequently isolated the fungus from lesions caused by the blotch fungus (*P. solitaria*) on apple fruits sent from Indiana. As previously noted, the fungus frequently follows fire blight and winter injury. Morse and Lewis (1910) state that in Maine orchards much of the disease that was called canker had its origin in frost spots of 1906–1907, and that so far as investigated the cankers of fruit trees in Maine orchards had their origin in wounds.

PYCNOSPORE GERMINATION (Fig. 29). The pycnospores usually germinate readily in tap or rain water. The time required for the process varies considerably, depending, no doubt, on the age of the spores. If they overwinter, the question of their longevity arises. As a rule sexual spores are regarded as short-lived, but it is not so in the case of this fungus. Duggar (1909:353) says: "The spores seem to retain their vitality for a considerable period of time, having been germinated after being stored for a year in the laboratory." The writer has found that spores two years old or older may germinate in tap water after twenty-four hours. Younger spores ordinarily germinate within five or six hours, but they may produce a tube after three hours. Spores which are dark brown in color, often septate, and having an older appearance, require more than twelve hours for germination.

Usually one or two tubes emerge from a spore at or near the end; germinations also occur at the side. The developing hyphæ in culture occasionally form microconidia, or secondary conidia, near the growing point of a hypha; these have been mentioned by Delacroix (1903 a:139), who states that they do not develop further. The writer has germinated them in tap water. In some cases peculiar types of germination occur, short, stunted tubes being developed. In other cases the process is entirely inhibited, and in certain of these cases the laying down of a cross-wall takes place instead. In one observation notes were made as follows:

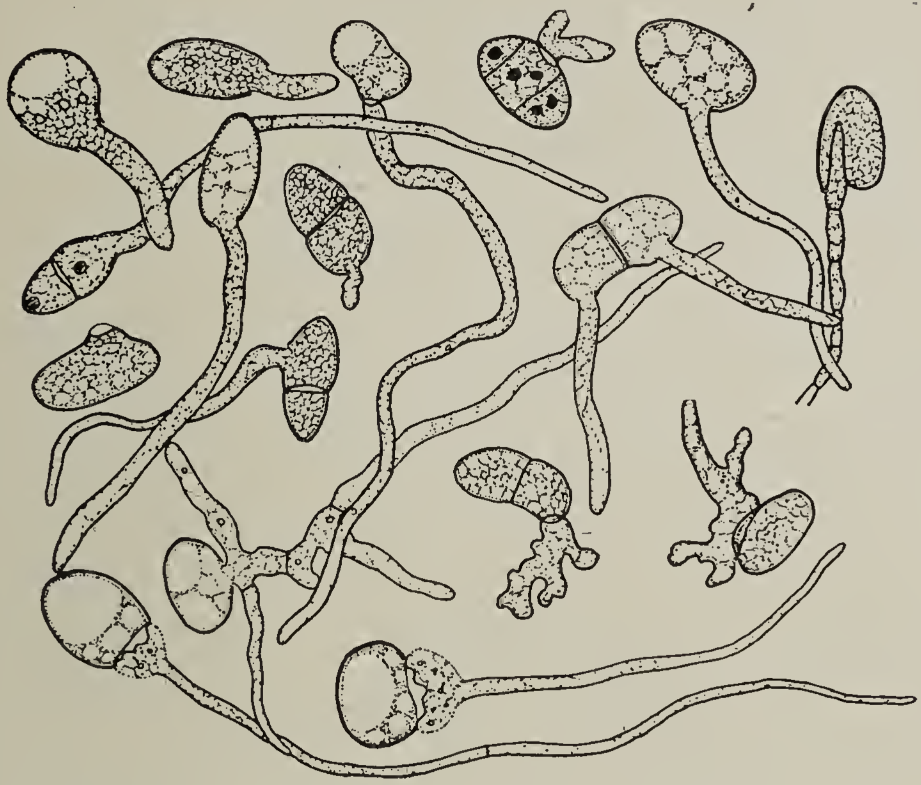

FIG. 29. TYPES AND VARIATIONS OF PYCNOSPORE GERMINATION

> Spores one-celled when collected (May 13, 1913). Placed to germinate in tap water and after twenty-four hours the two-celled spores had not germinated; the one-celled spores had developed tubes about 30 μ long. After forty-two hours some of the two-celled spores developed tubes about 175 μ in length, whereas the germ tubes of the one-celled forms were about 500 μ long.

Again, spores placed to germinate, instead of producing a germ tube, after several days developed a septum. Another peculiar behavior of the spores is that they may fuse in pairs. Delacroix (1903 a) describes a peculiar type of germination of young and hyaline pycnospores in a solution of 2.5 per cent of glucose and 1 per cent of peptone. No cross-wall was developed. After the third day the wall broke and the contents emerged, forming a bud on the surface of the spore. This spherule may attain a diameter of from 35 to 40 μ; its further development was not followed by Delacroix. The writer has observed similar behavior of pycnospores, except that the swollen parts finally developed a germ tube. This took place in tap water. In some cases older spores burst and fail to send out a germ tube.

The effect of low temperatures on pycnospore germination was noticed in the spring of 1913 in connection with infection experiments. On May 15, 1912, spores in drops of tap water on a glass slide were placed in a petri dish, plenty of water was supplied to prevent drying out, and the culture was placed out of doors, where the temperature ranged between 8° and 10° C. A second culture was kept at room temperature (21° C.). No germinations occurred outside, but the cultures kept in the laboratory at 21° C. gave normal germinations. On May 12, 1913, the minimum temperature was 9° C., the maximum 15.5° C. All spores out of doors failed to germinate at these temperatures, while those at 21° C. gave normal germination. On May 13, 19, and 20, 1913, when the maximum temperature was 15.5° C., similar results were obtained, except that in one culture on May 20, at 15.5° C., a very low percentage of germination was observed. This indicates that in most cases a temperature of 15.5° C. is unfavorable for germination, and that below that point germination fails. Delacroix (1903 a: 139) states that mature spores germinate after forty-eight hours at a temperature of about 16° C. (60.8° F.).

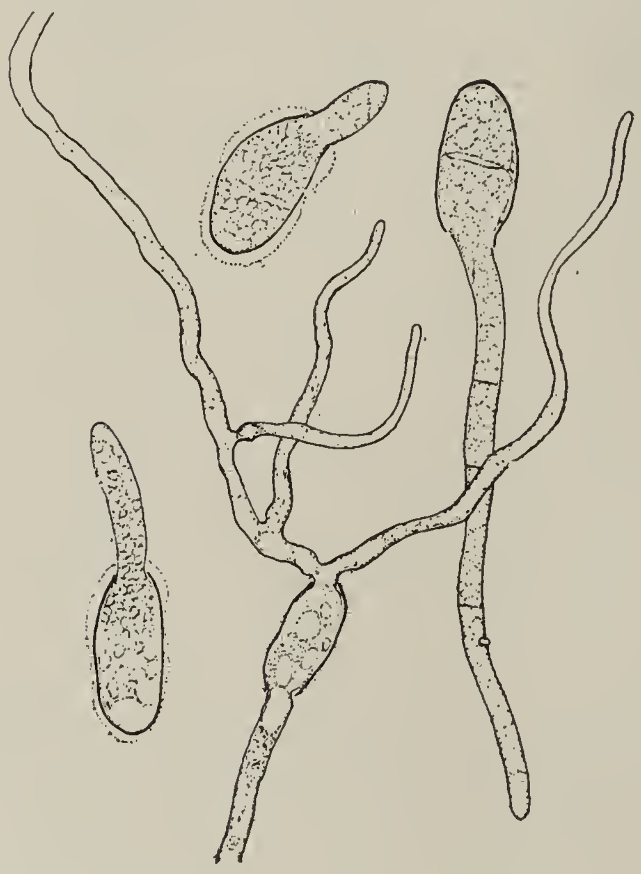

FIG. 30. STAGES IN THE GERMINATION OF ASCOSPORES

ASCOSPORE GERMINATION (Fig. 30). The ascospores germinate readily in tap water and potato agar. The time required for the process is from six to twelve hours. In some cases a septum is developed in the ascospore during germination.

INCUBATION PERIOD. The period of incubation on apple bark, as stated by Potebnia (1907: 16), is about four days. On foliage it is about five days, according to the observations of Scott and Rorer (1908: 50–51). Inoculations made by the writer on bark show that the time between inoculation and the first sign of the disease is from two to seven days, varying with the strains of the fungus used and the meteorological conditions. The average is four days. On fruit, discoloration appears after from twenty-four to forty-eight hours.

PATHOLOGICAL HISTOLOGY. *Fruit.*— If a section of an apple fruit is made perpendicular to the surface, the cuticle, epidermis, hypodermis, cortex, and scattered vascular bundles are in evidence. The epidermis is composed of a single layer of rectangular cells, the outer walls of which are strongly thickened by a waxy infiltration to form the cuticle. Immediately below the epidermal cells is the hypodermal parenchyma, the cells of which are distinctly different from those more deeply seated. They are compactly arranged, comparatively small, and oblong, with the greater diameter parallel to the surface. They contain the coloring matter of the fruit. There is a gradual transition from these cells to the large isodiametric cells that make up the mass of the apple tissue. The veinlets come from ten main veins and by continued branching the bundles become scattered, being finally lost in the cortex.

There is a sharp line of demarcation between the healthy and the diseased tissues (Plate XII, 2); this is especially noticeable in the hypodermal parenchyma. The coloring matter is abundant in the normal cells of the hypodermis; at the junction of the two regions the coloration is lost very abruptly and the tissue is a distinct brown. All the affected region is brown and the discoloration in the cortex extends beyond that in the hypodermis. Apparently the hypodermis is attacked along the advancing margin of the lesion from the cortex below. The mycelium of the fungus is found in advance of any apparent change in the normal color, and is found in the cortex first, at a point several cells in advance of the affected hypodermal cells. The hypodermis appears to be undermined. The walls of the cells in this region are greatly thickened; the process is apparent within a week after infection, and when the apple becomes mummified the lumen of the cell is nearly closed. Dandeno (1906) states that there is a production of cellulose in the cell wall of the apple in the course of its decomposition. Starch is also produced in the cells invaded by the mycelium of the fungus, but with the thickening the starch grains disappear. The excessive thickening is regarded by Dandeno as resulting in the preservation of the mummy.

The mycelium is usually, if not always, intercellular. In thick, freehand sections strands may be found crossing the cell cavity, but cell-wall penetration has not been observed. Frequently small threads appear to pass into the cell of the host from the parent branch which is in the intercellular space, but no opening in the host-cell wall has been seen.

Such hyphæ are regarded as being intercellular, merely giving the appearance of an intracellular habit because of the thickness of the section; in thin, microtomed sections the threads are found between the cells. In certain cases the hyphæ appear to be within the cells, but one may mistake a large intercellular space for a cell lumen. Dandeno (1906) states that the mycelium is intercellular, but that small threads enter the cells and even pass through them (Fig. 31).

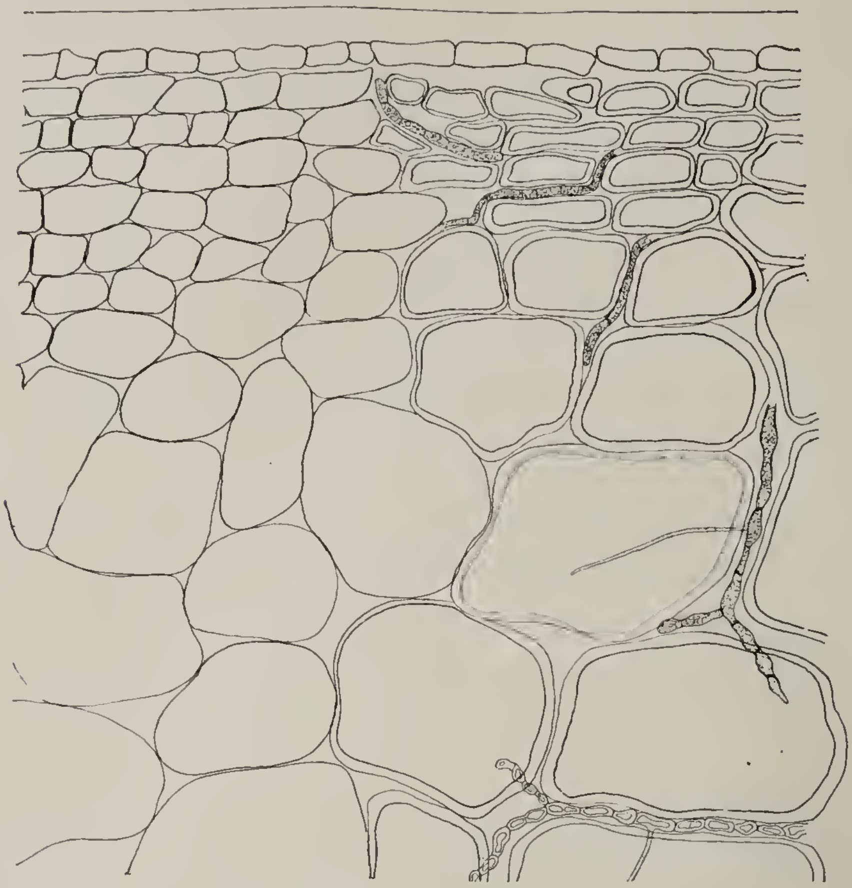

FIG. 31. HISTOLOGICAL CHANGES IN THE FRUIT OF APPLE

Showing appearance of healthy tissue at left and diseased tissue at right, and the mycelial relationship to the host cells

Leaves.— The lesion produced on the leaf is largely necrotic. The cells are brown, collapsed, and obviously dead. The average thickness of the normal apple leaf is about 142 μ, whereas that of the diseased area is about 61 μ (Fig. 32).

The epidermal cells of the affected tissue are flattened and bear little resemblance to normal epidermis. The palisade cells maintain their relative position but are considerably shortened. The cells of the spongy parenchyma are shriveled and irregular in form (Fig. 32).

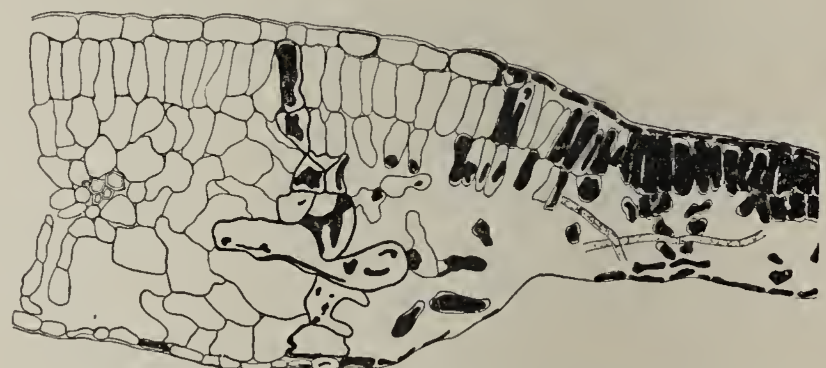

FIG. 32. HISTOLOGICAL CHANGES IN DISEASED LEAF TISSUE

Showing healthy and diseased tissue. The beginning of the suberized layer, represented by heavy-walled cells in a line from epidermis to epidermis, should be noted

In some cases the lesions are limited by a vein, and, although a small vein may mark the extent of the diseased area, the larger veins more frequently act in this capacity. In cases in which the edge of the spot does not fall at a vein, a plate of cells surrounds the lesion and limits, for a time at least, the extent of the fungus.

The structure of the leaf at the margin of a spot is very different from either the healthy or the dead parts. The process of differentiation apparently takes place in considerable advance of the fungus. In some stained sections a row of cells with dark-stained walls is seen in the leaf (Fig. 32). They are arranged in a direct line from the upper to the lower epidermis. This involves the palisade cells and the spongy parenchyma, the latter tissue now being composed of more densely packed, but large, cells. With the advance of the fungus this layer increases in size and number of cells until the diameter is increased over that of the normal part. An additional layer of palisade cells may be developed in this region, but in a late stage the entire mesophyll becomes densely filled with large, irregularly shaped cells. The elongated palisade cells are completely changed and become isodiametric in form. The apparent stimulation results in hyperplasia and metaplasia of the palisade cells and in hyperplasia of the spongy tissue (Fig. 33).

The diseased cells give a test for suberin with chlor-iodide of zinc and with cyanine-glycerin. Certain stages in the development of the leaf spot show discoloration of the epidermal cells up to the suberized layer only. Later, however, the epidermal cells are affected beyond this region, as evidenced by their loss of normal size and color. It appears that penetration of the temporary layer is accomplished by the fungus invading the epidermal cells and thence advancing into the healthy tissue. At any rate the mycelium is found in the epidermal cells in this region. The alternate processes of the formation of this layer of tissue, and the subsequent invasion of the tissue beyond the suberized layer by the parasite, give rise to the concentric rings previously described.

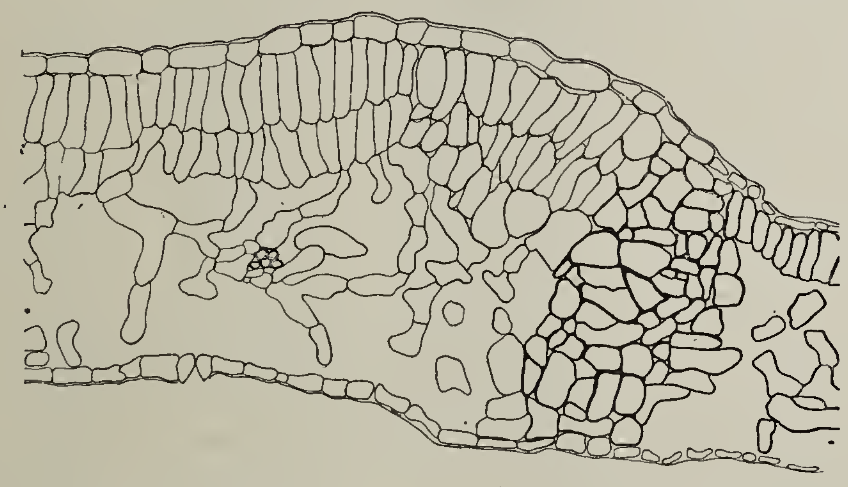

FIG. 33. HISTOLOGICAL CHANGES IN DISEASED LEAF TISSUE

Showing the reactions of the host along the margin of the lesion. Metaplasia and hyperplasia are exhibited in the mesophyll

Bark.— The tissues of the normal apple stem represent the condition found in a typical dicotyledonous plant. In the center is the pith, radiating from which region are alternate medullary rays and fibrovascular bundles. Outside these is a cylinder of secondary cortex, which is in turn surrounded by a cylinder of thick-walled cortex (probably primary in nature) and one of cork or periderm. In older stems the epidermis is not present. The secondary cortex is composed of several layers of phloem, in turn made up of hard, or lignified, sclerenchyma fibers, sieve tubes, companion cells, and phloem parencyhma. In a longitudinal section the medullary rays are prominent and are perpendicular to the periderm. In the secondary cortex these rays are connected by rows of phloem parenchyma which are oriented at right angles to the direction of the medullary rays. These phloem parenchyma cells are rectangular and similar to the medullary ray cells; the arrangement of the former results in the noticeable stratification of the secondary cortex.

The material for comparative study of healthy and diseased tissues was usually taken so that both areas would appear in the same section. Cankers from natural and artificial infection were fixed in Gilson's fixer or in chrom-acetic acid, hardened in the usual manner, and finally imbedded in either celloidin or collodion. Sections made from such material, as well as from fresh tissue, were cut with a desk microtome and stained with the following stains: safranine and methyl blue; safranine and methyl green; phloroglucin; and a chlorophyll solution.

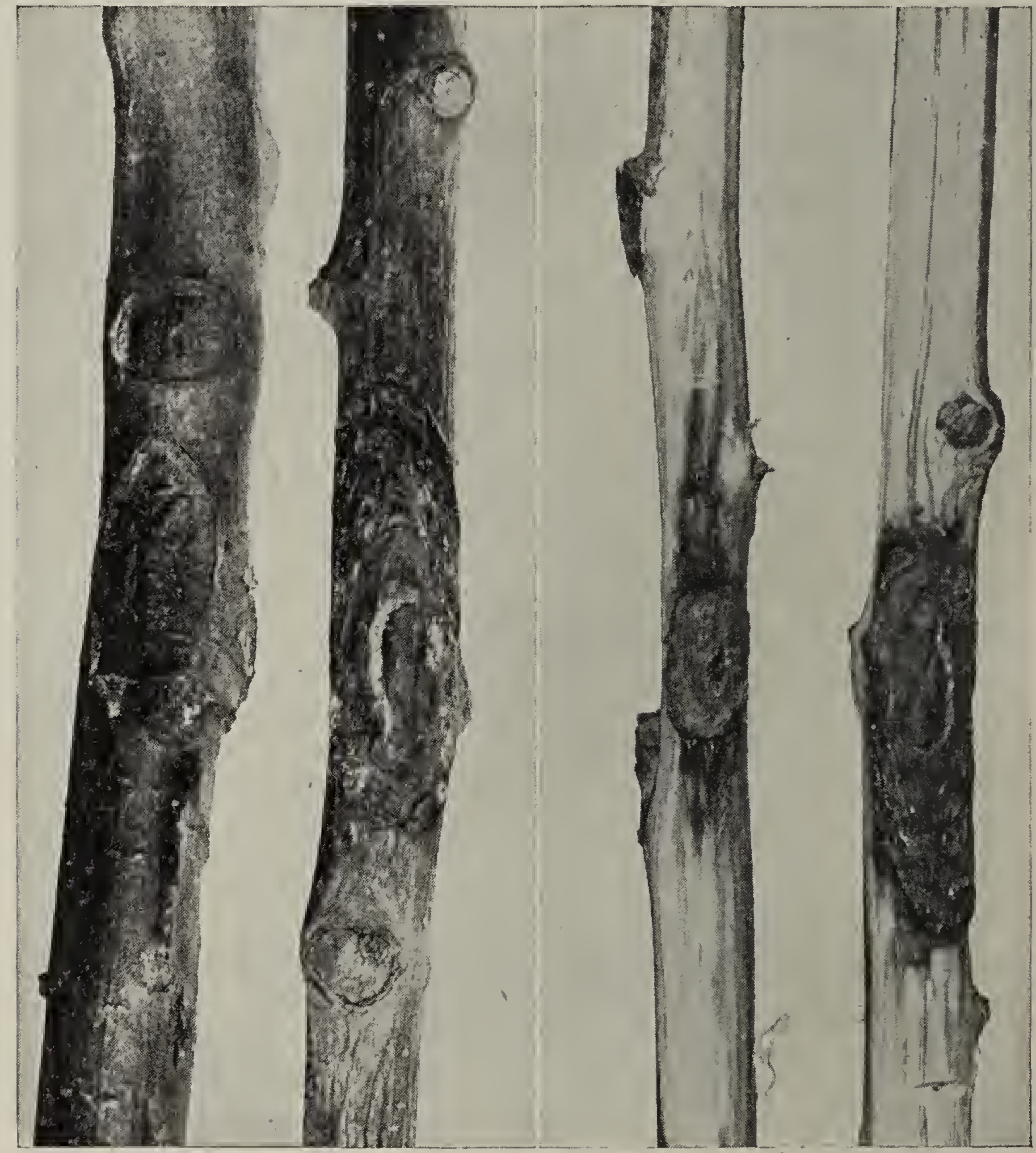

FIG. 34. HISTOLOGICAL CHANGES IN DISEASED WOOD

Two apple twigs, showing cankers as they appear on surface. The specimens on the right are the same twigs, with bark removed to show the streak

In the normal tissues the lignified and suberized tissues — that is, cork and hard sclerenchyma fibers — are stained red with safranin, whereas the cellulose tissues, cortical and medullary, are colored blue with methyl-blue and unstained with methyl-green. The woody parts stain red with phloroglucin. In the diseased part there is a very prominent general brownish deposit, located chiefly in the medullary ray cells, the thick-walled cortical parenchyma, and the phloem parenchyma. Such cells are not stained by any of the stains used. The sclerenchyma fibers and the cork are colored red by safranine, whereas suberized cork cells are made green with a chlorophyll solution. Diseased wood shows a test for lignin phloroglucin.

The more striking external symptoms of the canker noted are the discoloration of the bark, a crevice at the margin of the lesion, and a sinking of the tissues. It has been noted elsewhere that the organism penetrates the wood to a limited extent only, so that the more notable changes occur in the bark. The canker is sometimes superficial, the attacks of the organism being confined to the cortical tissues. Attacks on the wood of old limbs are not frequent, but on twigs the wood is subject to common invasion by the parasite. In cross and longitudinal sections the first and the second, and sometimes the third, layers of wood, and even the pith, are discolored. Closer examination shows the mycelium to be very abundant within the vessels of the xylem and in the woody parenchyma. In this region the characteristic brown deposit is found, but is located chiefly in the cells of the medullary rays and the wood parenchyma. Inoculations on young apple trees in the greenhouse with the ascospore strain (no. 82, from apple) show that

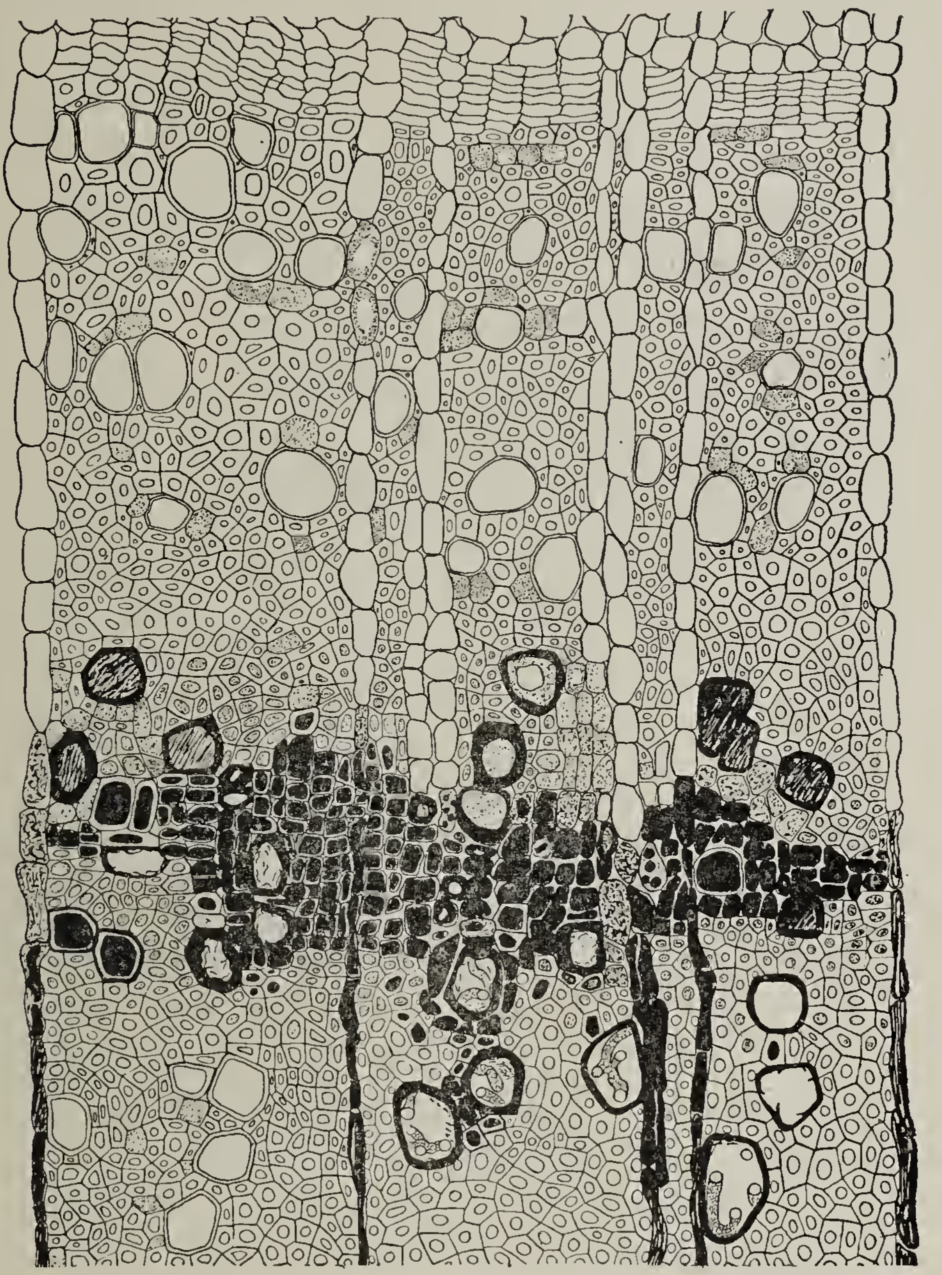

Fig. 35. histological changes in diseased wood

Cross section of part of apple twig, showing brown deposit in wood fibers and wood parenchyma cells. Mycelium is also shown in the xylem ducts, but it should be noted that none is found in other woody elements there is a streak developed in the outer layers of wood (Fig. 34), just as in the twig blight on chestnut oak, *Quercus prinus*, as reported by Ingram (1912) and noted subsequently by Rankin (1914). The streak is due to the discoloration of the cells, not to the presence of the mycelium (Figs. 35 and 36). One has only to examine longisections through the streak to be convinced that the hyphal threads do not grow in strands and are not otherwise arranged so as to give such an appearance to the tissue.

In the case of the more superficial cankers the ingress of the fungus is cut off from the healthy tissue by the development of a cork layer (Fig. 37). Such lesions reveal in section the presence of a layer approximating the normal periderm, with which it is continuous and which reacts the same with safranine and with a chlorophyll solution. These cells in their final state are suberized.

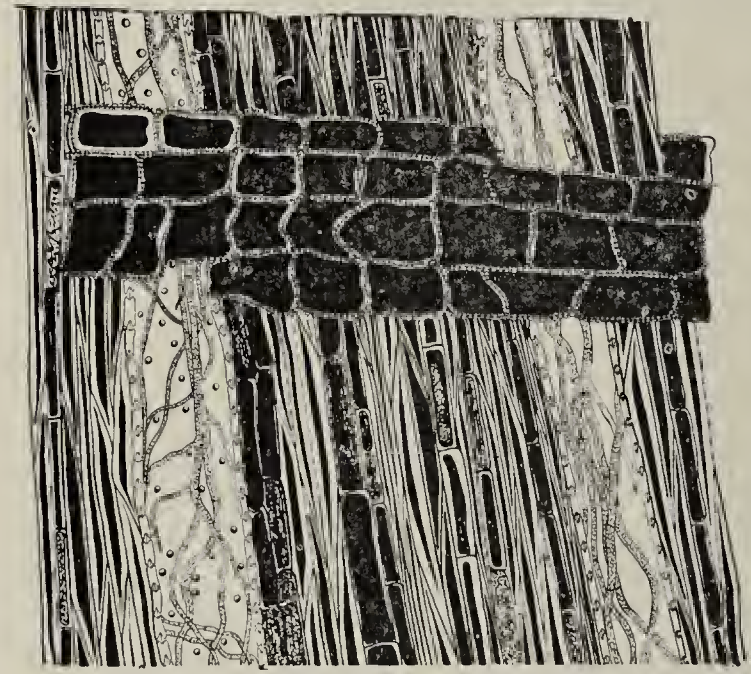

Fig. 36. HISTOLOGICAL CHANGES IN DISEASED WOOD

Longisection of a part of apple twig, showing brown deposit in woody elements. Mycelium is again to be seen in the xylem ducts

The layer originates by the division of cells of the cortical parenchyma. The sclerenchyma fibers are not changed. If the layer comes in contact with a group of sclerenchyma fibers it is interrupted. The more recently affecte cells—that is, those nearest th margin of the lesion—show a reddish tinge with safranine, indicating slight suberization throughout the region. Later, evidence of the cork layer is found just beyond the infected zone. Walls are laid down to form rectangular cells characteristic of the final cork layer and of the normal periderm. At this time they do not take the safranine, indicating that suberization has not begun. Such sections stained with chlorophyll solution also show no suberin reaction.

A later examination of the marginal layer between healthy and diseased tissue stained with safranine will reveal three distinct and characteristic zones, as follows (enumerating entad): a red layer of three or four suberized cork cells; a colorless layer of about two non-suberized cells, rectangular; and a third layer of about two smaller cells of the same shape bearing a brownish deposit, making a distinct brown line. Many slides show the reverse relation with respect to the suberized and cellulose layers; the colorless layer, composed of cells with cellulose walls, may lie next to the diseased tissue, and the cells with suberized walls next to the brown line.

This raises the question as to which cells are suberized first. The assumption is that those cells nearest the diseased zone are suberized first. This would be expected, in such a case, where response to injury is made by the host. But this scarcely explains the cases in which the colorless layer borders the affected tissue. In these cases, however, the brown line is not so distinct as described above, and often is not in evidence; so that this may stand as a younger stage in the formation of the cork layer. The cells of the suberized layers do not react alike when stained with safranine. A row of cells in the center is the darkest, the color shading off on both sides, perhaps indicating the amount of suberization.

The majority of the cells of the layer are densely granular, are thin-walled at first, and possess large nuclei. These have the characteristics of rapidly dividing cells.

A section through a canker having a crevice at its margin shows that the break follows the brown line. The dead tissues on the one hand shrink, while the living, normal part increases in diameter by growth, exerting tension on all tissues of the bark, and the break results. It appears that the cells making up the brown line are the weakest, and thus they mark the line of separation of the diseased from the healthy tissue.

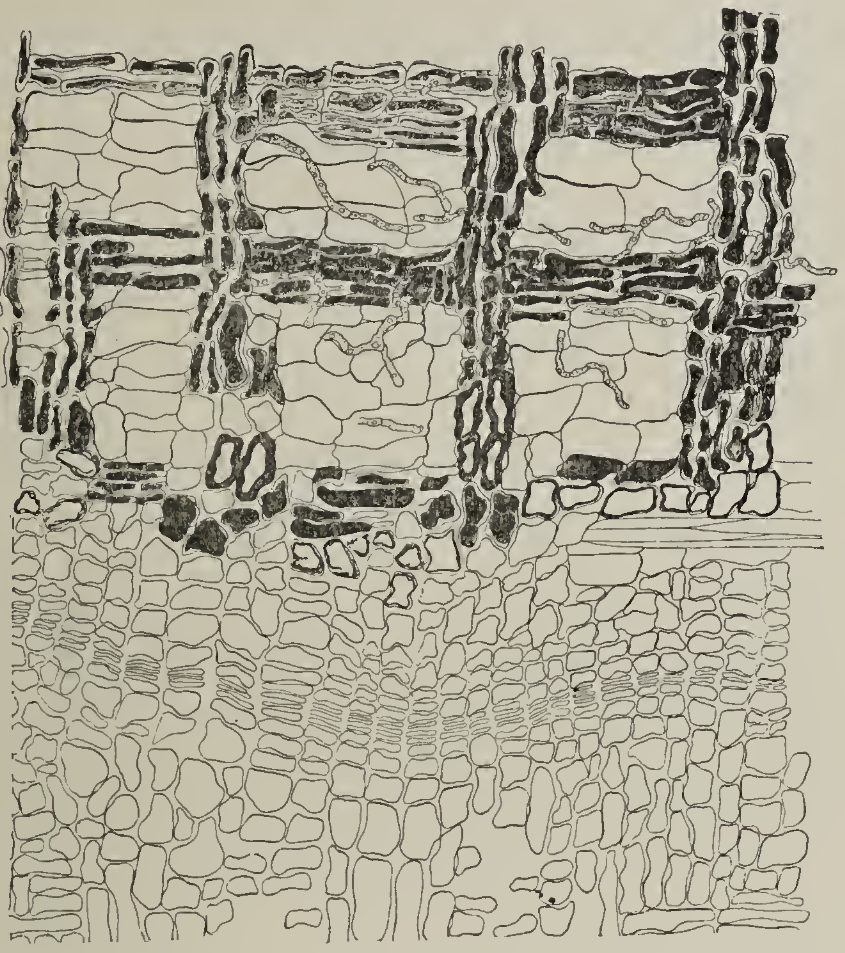

FIG. 37. HISTOLOGICAL CHANGES IN DISEASED BARK

Showing brown deposit in the medullary ray cells and phloem parenchyma, which cross at right angles resulting in a stratified appearance in the phloem. Below the diseased region is seen the cork layer

Along the marginal layer diseased pockets occasionally are formed which extend into the healthy tissue. Such areas are always in the region of a group of sclerenchyma fibers. A cork layer surrounds the pocket. Cross sections may be cut so as to include only a portion of one of these pockets, making them appear as internal, separate infections. Serial sections, however, always reveal their connection with the originally infected tissue.

In the diseased region are found the same stratified layers as mentioned in the survey of the normal secondary cortex. But in the affected areas both the cells of the medullary rays and the phloem parenchyma stand out very prominently, being filled with the brownish deposit. The remainder of the old phloem elements, the sieve tubes, companion cells, and sclerenchyma fibers, are not discolored at all. (Fig. 37.)

The brown mycelium of the fungus is found very abundantly throughout the diseased area. It is intercellular, except when it encounters the xylem and the hard sclerenchyma fibers; it is not easy to say just what the relationship is with respect to hard sclerenchyma fibers. It is noted elsewhere that the hyphæ are found within the tracheal tubes. The threads for the most part pass up and down the stem. This is in accordance with the external symptoms of a lesion. It has been stated previously that where the cork layer encounters a group of sclerenchyma fibers it is interrupted, and the fungus breaks through the barrier as laid down by its host. There is no evidence that the suberized cells are ever penetrated. Mycelium is found advancing through the layer at points where the sclerenchyma fibers cross it, a discoloration precedes the hyphæ, and almost before the threads get into the healthy tissue the latter is changed in its normal color. Very soon after is found evidence of a secondary cork layer, which usually branches from the primary layer at some point beneath the point of secondary penetration. This extends around the newly affected region, finally passing above to the normal periderm. Repetition of this process, accompanied by the formation of crevices at each successive cork layer, results in the concentric lines or cracks so characteristic, externally, of the lesion. The drying out and death of the cells results in their collapse, and the affected part shrinks.

CONTROL

BLACK ROT

EXCLUSION BY LEGISLATION

As previously noted (Evans, 1910), the British Government at Cape Colony has legislated against black rot. Importers are warned that, under a government notice of 1908, all consignments of pomaceous fruits found infected with this organism to the extent of one per cent and upward will be destroyed on arrival at the Colony or returned to the consignor.

SPRAYING

It was suggested by Sturgis (1893 b) that spraying in August and September would prevent black rot of quince. The following year the same author (1894) found that a 0.03-per-cent solution of copper sulfate is fatal to the fungus. More recently Waite (1906:19) recommends the same treatment as for apple scab. Wolf (1913) concludes from experiments conducted in Alabama that bordeaux 4-4-50, applied as follows, will be effective: the first spraying, about July 15, when the disease is just appearing; the second, two weeks later. This schedule gave satisfactory control, the sprayed fruits showing less than one per cent diseased on certain varieties. Control was less complete on Black Ben Davis, which exhibited from ten to fifteen per cent of black rot. Lime-sulfur was found to be wholly ineffective under southern conditions in 1912.

It should be remembered that frequently infections follow the work of the codling moth, and, as stated by Clinton and Britton (1910), the control of this insect lessens the amount of rot starting at such centers. The work heretofore described indicates that certain insects carry the spores; it is therefore important to consider the control of these pests.

HANDLING OF FRUITS

It is apparent from the life history studies that spores of the black rot organism are present in the orchard at picking time and are carried into storage. It has also been learned that the fungus effects penetration only through injured tissue. Consequently one factor in obtaining apples of good keeping quality is the elimination of mechanical and other injuries to the fruit; the occurrence of black rot in storage is undoubtedly connected with the handling methods in use in the orchard.

STORAGE

It has been found by Lamson (1902:81), and subsequently by Eustace (1908), that the temperature of the storage room should be about 31° to 34° F. (−0.5° to 1.1° C.). Higher temperatures allow growth of the fungus. It is important to note that when apples are stored in barrels, about one week is required for the temperature of the center of the receptacle to become equal to that of the storage room.

LEAF SPOT

SPRAYING

It seems that Alwood (1892) was the first to advocate the use of sprays for leaf spot. He recommends two applications, as follows: the first, just as the petals have fallen from the apple, using bordeaux mixture 4–5–50; the second, about twenty to twenty-five days later. The recommendations of later writers differ in number of applications and in type of fungicide. It is very apparent that the number of sprayings in a given year will depend on the character of the season. Ordinarily two or three applications are necessary, according to Brooks (1909, and 1912, a and b) and others. In certain seasons of considerable rainfall additional sprayings may be necessary.

As previously noted, in some districts at least the leaves are infected shortly after they unfold from the bud, and infections may continue throughout the spring according to Brooks (1909:124). Later Brooks and DeMeritt (1912:188) conclude that the period of infection extends throughout the middle of the summer. The number of applications then to be made will depend on the character of the season and the abundance of spores present.

In some sections of the country where apple scab also is to be combated, the regular scab sprayings have been generally recommended as sufficient. These are given by Wallace (1913:589–590) as follows: the first, when the blossoms show pink; the second, after the blossoms fall; the third, two or three weeks later. If later scab sprayings are necessary, the leaf spot will be controlled. Scott (1906:33) states that the disease may be controlled in connection with the treatment for bitter rot; for the latter disease he recommends from four to six applications of bordeaux mixture, made at intervals of two weeks beginning about six weeks after the trees blossom.

Apparently bordeaux mixture has been most commonly employed for leaf spot. Brooks (1912 b:15) maintains that it is the most effective fungicide for apple diseases, but points out that an objection to its use lies in the fact that spotting of the foliage and russeting of the fruit are likely to occur if showers follow its application. The spots produced on the leaves resemble those caused by the fungus. For leaf spot alone, Brooks (page 8 of same reference) finds that self-boiled lime-sulfur best holds the disease in check.

Lime-sulfur is regarded by Brooks (1912 b) as a satisfactory substitute for bordeaux, and in a later publication Brooks and DeMeritt (1912) show that commercial lime-sulfur at a strength of one gallon to twenty-five gallons of water reduced the infection from about 95 per cent to 26 per cent. When used at a strength of one gallon to fifty gallons of water, the lime-sulfur was found to be less effective. Brooks considers this fungicide about as efficient as bordeaux, and, because of the injury from the latter, lime-sulfur would appear the more desirable.

CULTIVATION

Brooks and DeMeritt (1912) have observed marked contrast between the amount of infection in sod and in cultivated orchards. They record the former as showing 0.79 spot per leaf, whereas in the latter there was only 0.47 spot per leaf. They say (page 189 of reference cited):

> The trees had been treated alike in every other respect and were of equal vigor when the experimental work was begun; it was, therefore, evident that cultivation had reduced the disease almost one-half. This reduction was probably partly due to the fact that the leaves were plowed under on the cultivated plots, but the lack of general vigor in the trees on the sod plots was apparently partly responsible for the difference.

CANKER

HISTORICAL AND INTRODUCTORY

The control of cankers has been a matter of consideration for some time. Nearly three centuries ago Parkinson (1629:550) recommended surgical methods together with a wound dressing of vinegar. Similar advice is given by Harrison (1823:342), who suggests a dressing of soot, water, and train oil. He recommends drainage of the soil in severe cases.

In more recent times, beginning with the appearance of the work of Paddock (1899 b), the recommendations are all essentially of the same nature. The employment of the common methods of orchard management — cultivation, fertilization, pruning, and spraying — is recommended, in order to promote general vigor. Keeping the trees in good growing condition is claimed to be essential (Warren and McCourt, 1905). Spraying to protect the bark is frequently recommended (Bethune, 1909:30, and others), while scraping the bark and applying a wash is suggested by Paddock (1899 b:190) and others. Pruning of diseased limbs and the growing of a new top is being practiced by some growers.

The control measures more commonly employed by the growers of New York State are pruning and spraying; other measures, as determined by circular letters and personal observation, are surgery, cultivation, fertilization, and mulching. The success of these methods varies and seems to depend on the vigilance with which the grower pursues the disease.

SURGICAL METHODS

PRUNING. In pruning for the control of canker, two methods may be employed: the limb may be cut from the tree entirely, or the cankered bark may be removed. In either case a wound will result and the application of a dressing becomes essential.

Removal of limbs.— The question frequently arises, when shall only the canker be cut out, and when is it necessary to remove the limb? No general rule can be laid down, but each case must be examined carefully and procedure taken accordingly. If the limb is large and productive, its removal should be postponed. This is commonly the practice. But to wait until the limb is not producing satisfactorily usually means that the canker will aid in bringing the branch to destruction. In such cases it is advisable to prevent the loss by eradicating the cankered spot by surgery.

If the limb is not producing, whether large or small, its removal for the purpose of eliminating the fungus is the alternative. The cut should be made so that another limb, or water sprout, may be allowed to grow in the approximate space left by the part removed. This method of treating the New York apple tree canker is employed in certain orchards along the Lake Ontario belt in this State. One grower is very successful in this measure of control. This, with protection from new infections by careful spraying of the entire tree — trunk and limbs — renders even the highly susceptible Twenty Ounce variety practically free from canker.

Grafting of stubs left by the pruning of the affected parts of limbs is occasionally practiced. This may be justified in certain cases, although as a rule it should be supplemented in the main by the method just described.

Removal of diseased bark.— The cutting out of cankers is a method to be employed when the grower is satisfied that the value of the limb warrants it. An attempt to remove all kinds and sizes of cankers from an infested orchard without regard to such a consideration is likely to result in the discouragement of the orchardist with the whole undertaking. The equipment necessary for use in the removal of cankered bark consists of a drawshave and a farrier's knife. The limits of the diseased area are ordinarily determined by making an external examination of the canker. Where this method is not reliable, small bits of the outer bark may be removed, following the line of the discoloration until the limits are determined. Similarly the depth of the canker is defined.

The shape of the cut will vary somewhat with that of the canker to be removed. So far as possible, the wound when finally finished should be lenticular in form. This will facilitate callus formation. If the wound is rectangular the upper and lower edges heal more slowly. The edge of the wound should be perpendicular to the long axis of the limb, for cuts made at a slant will result in a certain amount of dead cortex, which is undesirable from the standpoint of new infections. A possible exception to this method of trimming the margin is to be found at the lower end of the wound. Here the edge should be slanting enough to permit drainage of moisture.

WOUND TREATMENT. It is frequently advised that the wound should be disinfected and protected. The latter is certainly commendable practice, but whether the former is necessary will depend on the nature of the wound dressing.

Wound disinfection.— If the dressing itself is a disinfectant, a special disinfectant will not be necessary. In case one is needed, mercuric chloride at the usual strength (1–1000), or copper sulfate (1 ounce to 1 gallon of water), is most commonly used.

Wound protection.— The necessity of a protective covering for wounds is twofold: to check the weathering of the wound, and to prevent the growth of bacteria and fungi. It follows, then, that the fundamental requirement of a wound dressing is that it should be a preservative and a preventive. Briefly, then, the dressing should have antiseptic qualities, and should be fluid, reasonably inexpensive, and easily prepared and applied; it is essential that it should give complete covering; it must be impervious to air and water, must be durable, and must not injure nor kill the tissues nor interfere with the healing process.

The preparations now most commonly used are paint, tars, and asphaltum. In some cases commercial tree paints are employed. It is generally agreed that paints are an inefficient covering, whereas asphaltum once applied gives the desired protection. Asphaltum, however, is more difficult to apply. This is particularly true if the asphaltum used is rendered liquid by heat; if it is dissolved in gasoline it is more easily prepared and hence more available. The combination of asphaltum and gasoline has been applied rather extensively in the orchard of Fred Hazleton, at Leroy, New York, and from all appearances is commendable.

The writer has used coal tar for the past three years with good success. This is a residual tar derived in the manufacture of artificial gas from coal. According to Lunge (1909), tars may vary even from the same materials, depending on the temperature used in the distillation, the shape of the retort, and other factors. The use of coal tar as a wound dressing has been recommended to growers of the State, and some have complained of injury to the healthy tissue from its use while others report it as an appropriate material. Many cases of injury have been found to have resulted from the use of creosote, but not from coal tar. The pruner must distinguish between the two materials. The writer has never seen any cases of injury from coal tar on apple trees, and it has been used successfully on peaches by Jehle (1913). It is interesting to note a quotation from Des Cars as given by Bailey (1907:111–113):

> The application of coal tar should not be made except with considerable caution in the treatment of wounds on drupaceous fruits (cherries, peaches, plums, etc.), and especially on the plum tree. It has often been observed that the bark of fruit trees of this class has suffered from the application of coal tar. This is not the case, however, with pome-bearing trees (apples, pears, etc.); to these coal tar may be applied with perfect safety.

Card (1897:9) reports experiments in pruning in which he tested various materials for protecting wounds. He says of coal tar: "Coal tar, however, seems to have been a positive hindrance to the healing process, not one wound having been reported as healing extremely well, while the majority are reported as healing only fairly well." As a comment on this remark, Bailey (1907:113) says: "It is not said, however, whether the tar injured the tissues, or whether the apparent results may not have been due to the position and character of the wound quite as much as to the dressing. In my own experiments . . . . tar did no damage."

In view of the complaints made of injury from the use of coal tar, it occurred to the writer that this substance varied sufficiently in different parts of the State to account for the injury, if any ever occurred. Samples were obtained from the gas plants in the following cities in New York: Syracuse, Owego, Batavia, Rochester, Ithaca, Lockport, Buffalo, Albion, and Geneva. These samples were applied to wounds of mature apple trees on the farm of Dr. Johnson, at Leroy, New York, in August, 1912. Examination at intervals during the growing seasons of 1912 and 1913 showed equally good healing and no injury. Another orchard, near Batavia, New York, owned by Chapin & Son, has been extensively treated with coal tar, with results similar to those just described. The writer has applied coal tar to Northern Spy, Baldwin, and Hubbardston apples in an orchard at Byron, New York, and no detrimental effects have been observed. In some cases the wound has been disinfected by the use of mercuric chloride (1–1000), but no difference in the efficiency of protection was observed between wounds so treated and those not disinfected. The writer feels safe in recommending the use of coal tar without previously disinfecting the wounded surface.

The cost of canker treatment — that is, the removal of diseased bark and the application of a dressing — is not an easy matter to determine. Where it is done extensively the grower usually does the work along with the regular pruning, so that the cost of canker treatment alone can hardly be separated from that of the whole operation. In an apple orchard at Leroy, New York, careful work was done in 1912 by A. S. Davis. The orchard contained 950 forty-years-old trees. The orchard had been neglected for several years, and dead limbs, cankers, collar rot, and heart rot were abundant. Mr. Davis furnishes the following figures:

Cost of trimming	$407.90
Coal tar, 40 gallons, at 20 cents a gallon	8.00
Corrosive sublimate	.75
Applying tar	30.00
Removal and destruction of brush	54.70
Total	$501.35

The following data are taken from a similar orchard at Batavia, New York:

Miscellaneous data	
Number of trees	360
Age of trees	30 years
Cost	
Labor, 348 hours, at 25 cents an hour	$87.00
Coal tar, 10 gallons, at 15 cents a gallon	1.50
Corrosive sublimate	.50
Total	$89.00

It is seen that the average cost of the work in the Leroy orchard is about fifty-two cents a tree. It must be borne in mind that the orchard had not been pruned in several years, which accounts in part for the high cost of the work. In the Batavia orchard the average cost is approximately twenty-five cents a tree. These figures do not represent the cost of treating the cankers alone; this process itself would be considerably less than either of the above figures.

WOUND HEALING. *Wound cork.*— According to Hartig (1894:225), whenever the living phellogen is injured a new zone of phellogen, or cork, which is continuous with the cork layer along the edge of the wound, is formed from the uninjured cells which are situated deeper in the cortex. The cortical parenchyma, which lies beneath the periderm, possesses sufficient power of cell division to enable it to keep pace with the increasing thickness of the stem. But in the case of the wound its reproductive capacity is confined to the development of a periderm close beneath the surface of the exposed tissues. Its formation does not depend on the season of the year, but it may be formed even in winter.

Wound wood.— Hartig (1894:228) states that wood exposed by a wound has the power of producing new cortex and new wood when the cambium is active and when the cambium layer and young wood are protected from drought. In such a case, regeneration of the covering layers is effected. The cambial region consists of embryonic bast and wood, which is capable of growth and ultimately of a certain amount of differentiation. The wood thus formed is termed wound wood.

Callus.— Callus may be developed when the cambium has dried up or when it is absent from the surface of the wound. Its formation proceeds from the edge of the wound, beginning in the cambium. Hartig (1894:231) states that it is a purely mechanical process and results from the reduction of the bark pressure on these tissues. There is always a certain amount of tension in the cortical mantle, whereby a considerable pressure is exerted on the cambium. Should this pressure be locally reduced by a wound's reaching the wood, the processes of cell division and growth are accelerated not only along the edges of the wound but also at greater distances. The callus cushions advance from the edges of the wound, finally coming in contact and coalescing. This coalescence is retarded if the callus is clothed at an early stage with dead bark.

It has been noted that wounds made in cutting out cankers should be pointed in order to permit rapid healing. In this connection Hartig (1894:232) states that the formation of callus proceeds more vigorously in case of a longitudinal incision than when the incision is transverse. This is explained by the nature of the pressure by the bark in consequence of peripheral enlargement of the stem. The pressure here acts like that of a barrel hoop on the staves, and so callus develops more rapidly along the lateral margins of the wound. In this connection the question of slitting the lower edge of the callus arises. Reasoning from the data regarding the development of the callus, it seems advisable to practice this operation each year; this prevents the callus from bunching, and stimulates it to more ready occlusion of the wound.

SPRAYING

The effectiveness of spraying for canker is a question frequently raised. It is the belief of the writer that spraying as a preventive, but not as a cure, is worthy of attention. It is true, however, that growers report cases of curing canker by spraying. The fungus mycelium is protected by the bark; hence sprays will not reach it, and eradication of the fungus from a given lesion by spraying seems highly impossible. Spraying to protect healthy bark from infections would certainly appear advisable, but the data at hand are somewhat conflicting. The writer recalls an orchard in which canker does not occur. The trees are sprayed carefully each year, according to general recommendations for apples. Some of the trees are Twenty Ounce, but they are free from the disease. The limbs are kept coated with spray throughout the summer, and as late as the middle of August these trees are still covered. In contrast to this orchard, another is recalled which is severely affected with canker, yet the trees are given the regular sprayings. The difference in these cases may be accounted for by the lack of thoroughness of the spraying in the second orchard. Since protection is the principle involved in this method of control of canker, the success of any attempts in this direction is determined by the completeness of the covering.

GENERAL CONSIDERATIONS

The destruction of rubbish about the orchard is no new suggestion. Peck (1879:21) recommends that affected fruit should be removed from the orchard and destroyed. The destruction of fallen leaves is recommended by Alwood (1892). Sheldon (1905) and others suggest picking rotted fruit before the fungus spores mature in the case of quince black rot; Sheldon adds that this might not be possible with apples because of the size of the trees. In Alabama, however, Wolf (1913), as has been previously noted, controlled the disease by spraying. The opinion is held by Brooks and DeMeritt (1912:189) that affected leaves should be plowed under, while clean cultivation is the recommendation of Reed, Cooley, and Rogers (1912:5). The removal and burning of affected limbs is advocated by Bethune (1909:30) and others.

The ability of the fungus to pass from one part of the apple tree to another only adds to the sources of inoculum, so that sanitary measures become of special importance.

ORCHARD MANAGEMENT

The value of careful handling of fruit to prevent injury has been emphasized. This is based on the principle that the causal organism is a wound parasite. The same care should be exercised with reference to the bark of the tree; injury should be avoided whenever possible. Injuries to bark are likely to result from cultivating implements and harness, the careless handling of ladders while picking, and climbing over the trees with rough-soled boots. The importance of guarding against such orchard practice lies in the fact that cankers begin in just this sort of place.

It has been mentioned that the fungus follows winter injury. As a protection against winter injury, Reddick (1912:37) advocates early plowing in the spring, and cultivation to give the trees the advantage of conserved moisture; he recommends that cultivation should cease not later than August 1, in order to start the trees into maturation. Cover crops, to take up excess moisture in the autumn, should be sown. Soil drainage in low ground, and a good circulation of air, are important considerations.

When it is desired to grow varieties that are susceptible, the canker difficulty may be obviated to a considerable extent by working over the larger limbs of more resistant varieties to the one desired. This has been done with apparent success in a few instances. The difficulties involved are that pruning must be done every year to remove all sprouts from the stocks, and that renewal of old branches cannot be effected so readily. Such a treatment also throws the bearing area higher into the air, so that in the case of erect growers, such as Twenty Ounce, thorough orchard operations are made more difficult.

RESISTANT VARIETIES

Since certain varieties of the apple — for example, Esopus and Twenty Ounce — are more susceptible to canker than are other varieties, the growing of other varieties will undoubtedly render the problem of control less difficult. Twenty Ounce, however, is one of the most satisfactory fall varieties for commercial planting in New York State. The question therefore arises, whether the orchardist should sacrifice the growing of this variety in the hope of escaping the problem of canker control. The evidence at hand indicates that if a grower wishes to raise Twenty Ounce, his success in keeping the trees free from canker will depend on his efforts. Observations warrant this opinion. It is true that, as stated by Warren and McCourt (1905), "something more than thrifty growth seems to be necessary in order to prevent the destruction of the Twenty Ounce"; so that vigor in itself should not be given too much dependence. Wellcared-for trees of this variety are often severely cankered. It is assumed that the trees must be in a thrifty condition in order to give the best results, but the control problem does not end here, for vigor does not establish nor maintain resistance.

AN ENEMY OF THE PATHOGENE

Potebnia (1912)[8] reports an interesting case of a fungus, *Helicomyces Sphaeropsidis* Potebnia, living as a parasite within the conidia of *Sphaeropsis pseudodiplodia* [= *Physalospora Cydoniae*]. Infection takes place when the host (the conidia of *Physalospora Cydoniae*) is in the Macrophoma stage. He notes a similar case reported by Japp, in which *Helicomyces niveus* Bres. & Japp is parasitic on *Diplodia inquinans* West., and states that in Japp's herbarium specimen all pycnospores in the infected pycnidia were killed by this parasite.

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[8] Translated by C. D. Sherbakoff, formerly of the Department of Plant Pathology at Cornell University.

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Bethune, C. J. S.

1909 Fungus diseases and insect pests. *Also*, Cankers on apple trees. Ontario Agr. Coll. and Exp. Farm. Ann. rept. **34**:26–32.

Reports (p. 29) that cankers do great damage along the north shore of Lake Ontario. Says (p. 29) that spores of *Sphaeropsis Malorum* are carried by the wind.

1910 Black rot canker (Sphaeropsis Malorum). Ontario Agr. Coll. and Exp. Farm. Ann. rept. **35**:35–36.

States that black rot canker apparently can be successfully controlled by pruning out dead branches, cutting out cankers, and coating the bark with spray.

Bommer, E., and Rousseau, M.

1885 Florule mycologique des environs de Bruxelles, p. 3–353.

Sphaeropsis Malorum Berk. is listed (p. 257) on fallen apples.

Brooks, Charles

1907 Diseases of the apple. *In* Seventeenth and eighteenth annual reports. New Hampshire Coll. Agr. Exp. Sta. Bul. 129:267–270, pl. 15.

Records black rot and cankers due to *Sphaeropsis Malorum* Berk. as common; records leaf spot due to *Phyllosticta pirina* Sacc. and *P. limitata* Peck as serious, with little or no effect on it from spraying. States that majority of apple limb cankers are caused by *Sphaeropsis Malorum* Berk., and that few of the orchards visited did not show the disease.

1909 Black rot, canker, and leaf spot. *In* Some apple diseases. New Hampshire Agr. Exp. Sta. Bul. 144:123–126, fig. 20–24.

Discusses occurrence, symptoms, etiology, and control of black rot, canker, and leaf spot. Lists the following fungi as associated with these diseases: *Sphaeropsis Malorum, Coniothyrium pirina, Coryneum foliicolum, Alternaria* sp., and one of the Tuberculariae.

1912 a Black rot, canker, and leaf spot. *In* Some apple diseases and their treatment. New Hampshire Agr. Exp. Sta. Bul. 157:17–20, fig. 20–24.

Maintains that black rot does considerable damage in storage. Outlines sprayings which are said to be fairly effective for leaf spot.

1912 b Fungicides in the apple orchard. New Hampshire Agr. Exp. Sta. Bul. 161:1–15.

Compares different fungicides for control of leaf spot.

Brooks, Charles, and DeMeritt, Margaret

1912 Apple leaf spot. Phytopath. 2:181–190, pl. 17, fig. 1–6.

Give an account of the etiology of leaf spot, paying particular attention to the morphological and biological variations in *Sphaeropsis Malorum.* Infection shown to occur from the time the leaves unfold until the last of August. Cultivation, spraying, and the removal of cankers given as the important control measures.

Brooks, Charles, Fisher, D. F., and Cooley, J. S.

1914 Apple rots. Phytopath. 4:403. (Abstract.)

List several species of fungi, including *Sphaeropsis Malorum,* which were isolated from market and storage apples.

Bryce, P. I.

1915 Apple leaf-spot or black rot canker. Quebec Soc. Prot. Plants from Ins. and Fung. Dis. Ann. rept. 7:86–90. Illustrated.

Gives an account of symptoms, varietal susceptibility, and control of the disease.

Bubák, Fr.

1909 Ein kleiner Beitrag zur Pilzflora von Niederösterreich. Ann. myc. 7:59–62.

Sphaeropsis Mali (West.) Sacc. listed (p. 62) as collected on *Pirus Malus* in "Hohe Warte" bei Wien.

Burrill, T. J.

1907 Bitter rot of apples: botanical investigations. Illinois Univ. Agr. Exp. Sta. Bul. 118:553–608.

States that *Sphaeropsis Malorum* is sometimes associated with the bitter rot fungus in cankers. The former organism said to follow the latter under Illinois conditions.

Burrill, T. J., and Blair, J. C.

1901 Apple fruit-rots. Illinois Univ. Agr. Exp. Sta. Circ. 37:(12 pages, unnumbered). Illustrated.

Special attention given to symptoms of black rot, caused by *Sphaeropsis Malorum.* Suggestion that another species causes canker. Discussion on second and third pages.

Butler, O.

1912 Report of the Department of Botany. *In* Twenty-third and twenty-fourth reports. New Hampshire Agr. Exp. Sta. Bul. 163:16–17.

Mentions the work of Brooks, which appeared later in Phytopathology 2:181–190 and was published jointly by Brooks and DeMeritt.

Caesar, L.

1909 Black rot canker of apple trees. *In* Lime-sulphur wash. Part II.— Practical and popular treatment. Ontario Agr. Dept. Bul. 177:59–61, fig. 16.

States that on leaves and fruit the disease is seldom serious, but cankers often do great damage especially in Prince Edward County, Ontario.

1912 Black rot canker. *In* Our most troublesome orchard insects and diseases. Ontario Fruit Growers' Assoc. Ann. rept. 44:22, fig. 15.

Author is convinced that the fungus follows winter injury.

Card, F. W.

1897 Notes on pruning. Nebraska Agr. Exp. Sta. Bul. 50:1–10.

Concludes from experiments that lead paint is the best material for covering wounds; grafting wax said to be the next best; coal tar found to prevent checking, but seemed to hinder the healing process; pine tar and shellac reported as unsatisfactory.

Chase, W. W.

1913 Apple leaf spot. *In* Principal insects and diseases of the apple in Georgia. Georgia State Bd. Ent. Bul. 38:40–41, pl. 6, fig. 2.

Leaf spot caused by *Sphaeropsis Malorum* said to be one of the most destructive apple foliage diseases in Georgia.

Chester, F. D.

1901 a Canker in apple and pear. *In* Pear blight and pear canker. Delaware Coll. Agr. Exp. Sta. Bul. 52:6–8, fig. 4–7.

States that twigs and branches bearing pycnidia of *Sphaeropsis Malorum* Peck are sources of infection.

1901 b Canker in the apple and pear. *In* Report of the Mycologist. Delaware Coll. Agr. Exp. Sta. Ann. rept. **12**:43–46, fig. 4–7.

(Same as 1901 a.)

1902 Pear canker treatment. *Also,* Canker in apples. *In* Sundry notes on plant diseases. Delaware Coll. Agr. Exp. Sta. Bul. 57:8–11, fig. 5–6.

Describes symptoms and control of canker of pear and apple caused by *Sphaeropsis Malorum.*

Clement, F. M.

1913 Winter injury in orchards. Quebec Soc. Prot. Plants from Ins. and Fung. Dis. Ann. rept. **5**:24–26.

Says that frost wounds are made doubly serious if not treated to prevent the admission of the spores of saprophytic fungi, especially those of the black rot fungus, with the consequent development of apple canker.

Clinton, G. P.

1902 Black rot, Sphaeropsis Malorum Berk. *In* Apple rots in Illinois. Illinois Univ. Agr. Exp. Sta. Bul. 69:192–193, pl. B, fig. 2.

Sphaeropsis Malorum Berk. regarded as one of the chief causes of rotting of apples in market.

1904 Black rot, Sphaeropsis Malorum Pk. *In* Report of the Botanist. Connecticut (New Haven) Agr. Exp. Sta. Ann. rept. **27**:298, 342, 352, pl. 11, a.

Black rot regarded as one of the commonest and most universal diseases of the apple. Noted also on pear and quince.

1907 Winter injury and canker, Sphaeropsis Malorum Pk. *In* Report of the Botanist for 1906. Connecticut (New Haven) Agr. Exp. Sta. Ann. rept. **30**:310–311, pl. 17, a.

A peculiar limb disease of the apple is doubtfully attributed to winter injury and *Sphaeropsis Malorum.*

1915 Notes on plant diseases of Connecticut. *In* Report of the Botanist for 1913. Connecticut (New Haven) Agr. Exp. Sta. Ann. rept. **38** (1914):1–29. Illustrated.

Black rot noted on stored apples (p. 5).

Clinton, G. P., and Britton, W. E.

1910 Black rot, Sphaeropsis Malorum. *In* Tests of summer sprays on apples and peaches in 1910. Connecticut (New Haven) Agr. Exp. Sta. Ann rept. **33–34**:590, pl. 21, b.

Authors report occurrence of black rot (due to *Sphaeropsis Malorum*) on summer and stored winter varieties. State that the use of insecticides in keeping out codling moth lessens the rot starting from this cause.

Cook, M. T.

1913 Report of the Plant Pathologist. New Jersey Agr. Exp. Sta. Ann. rept. **33**:509–527.

Black rot of apple and quince, caused by *Sphaeropsis Malorum*, among the diseases listed (p. 512) as most important and most common in the nurseries.

1914 a Black rot of the apple and quince. *In* Some diseases of nursery stock. New Jersey Agr. Exp. Sta. Circ. 35:13–14, fig. 9.

Twig and leaf-spot forms of the disease very common in nurseries. It is advised that diseased trees should never be set.

1914 b Black rot (Sphaeropsis Malorum Pk.). *In* Most common diseases of the year. New Jersey Agr. Exp. Sta. Ann. rept. **34**:799, 809.

Black rot of apples most severe on Red Astrachan, Star, Lawver, Smokehouse. Black rot of quince reported as being very abundant and very severe.

Cooke, M. C.

1892 Sphaeropsis pomorum (Schwz.). *In* Sphaeriaceae imperfectae cognitae. Grevillea **20**:86.

Suggests that *Sphaeropsis pomorum* (Schwz.) [=*Sphaeria pomorum* Schwz.] is probably the same as *Sphaeropsis Malorum* Peck, of which *Phoma Malorum* Berk., erected by Saccardo, is possibly a younger condition.

Cooper, J. R.

1913 The control of canker in the orchard. Nebraska hort. **3**:2:1–2.

Black rot canker is ranked third in importance among cankers in Nebraska. The discussion of control measures is directed at the Illinois blister canker.

Corbett, L. C.

1900 Brown spot, frog eye. *In* Fruit diseases and how to treat them. West Virginia Agr. Exp. Sta. Bul. 66:202–204, fig. 2.

Author considers frog-eye, or brown spot (said to be due to *Phyllosticta pirina*), more injurious than either blight or scab.

Crabill, C. H.

1915 The frog-eye leaf spot of apples. Virginia Agr. Exp. Sta. Bul. 209:3–16, fig. 1–5.

Author states that frog-eye leaf spot is the most prevalent of apple foliage diseases in Virginia. The annual losses from the disease are said to be heavy in that State, but systematic spraying has controlled the disease in a satisfactory and effective manner. Symptoms are described. Etiological studies are tabulated, and from his experiments the author concludes that frog-eye spots are initiated by *Sphaeropsis Malorum.* All other fungi with which he deals are classed as facultative parasites, following *S. Malorum*, or as pure saprophytes.

Cummings, M. B.

1909 Apple orchard survey of Niagara County. Cornell Univ. Agr. Exp. Sta. Bul. 262:277–320, fig. 26–40.

Gives notes (p. 304, table 12) on economic importance of canker.

Dandeno, J. B.

1906 A stimulus to the production of cellulose and starch. Michigan Acad. Sci. Rept. **8**: 40–44.

Claims that the fungus *Sphaeropsis Malorum* stimulates the cells of ripe apple fruit to form starch and to thicken the cellulose walls. Suggests that starch is built up first and then dissolved and built into cellulose, the process going on until the fruit is mummified and dry, whereupon it is in a state of preservation.

Delacroix, G.

1903 a Sur un chancre du pommier produit par le Sphaeropsis Malorum Peck. Soc. Myc. France. Bul. **19**: 132–140. Illustrated.

Gives an account of the disease which, it is believed, appeared in France at least as early as 1901. Discusses the morphology of the parasite and the relationship of the mycelium to the tissues of limbs, mentions inoculation experiments, and suggests control measures.

1903 b Sur l'identité réelle Sphaeropsis Malorum Peck. Soc. Myc. France. Bul. **19**: 350–352.

Reports the examination of the following type material: *Sphaeropsis Malorum* Peck, *S. Malorum* Berk., *Diplodia maura* Cooke & Ellis, *D. pseudodiplodia* Fckl., and *Botryodiplodia Mali* P. Brunaud. Concludes that *S. Malorum*, *D. maura*, and *B. Mali* are all different, and that *S. Malorum* in France, *S. Malorum* Peck, and *D. pseudodiplodia* Fckl. are identical. States that since *D. pseudodiplodia* was described before *S. Malorum*, the latter name should disappear, and the new combination *S. pseudodiplodia* (Fckl.) G. Del. is proposed.

Dickens, A., and Headlee, T. J.

1911 Spraying the apple orchard. Kansas Agr. Exp. Sta. Bul. 174:251–292, fig. 1–19.

Give an account of experimental work in the control of black rot by spraying. Bordeaux mixture and lime-sulfur were used on several varieties.

Douglass, B. W.

1910 Black rot. *In* Plant diseases. Indiana State Entomologist. Rept. 2 (1908–1909): 135.

The disease is briefly described.

Duggar, B. M.

1909 Black rot and canker of pomaceous fruits. *In* Fungous diseases of plants, p. 303, 350–354, fig. 169–172.

A discussion of habitat relations, etiology, and control of the fungus.

Edgerton, C. W.

1908 Two little-known Myxosporiums. Ann. myc. 6:48–53, fig. 1–2.

Points out similarity and difference between the cankers caused by *Sphaeropsis Malorum* and a new species of Myxosporium, called *M. corticolum*. The synonymy of *S. Malorum* is given.

Ellis, J. B.

1880 On the variability of Sphaeria Quercuum Schw. Philadelphia Acad. Nat. Sci. Proc. 1879:66–70.

Author would include several enumerated species of Sphaeria, Botryosphaeria, Dothidea, and Melogramma under one species, and the name *Melogramma fuliginosa* is accepted. Ascigerous forms accompanied by stylospore forms of the Diplodia or Sphaeropsis type.

Ellis, J. B., and Everhart, B. M.

1892 The North American Pyrenomycetes, p. 1–793, pl. 1–41.

Eustace, H. J.

1908 Investigations on some fruit diseases. New York (Geneva) Agr. Exp. Sta. Bul. 297:29–48, pl. 1–7.

Shows by experiment that the fungus (*Sphaeropsis Malorum*) is not destroyed but its growth is retarded in storage at temperatures ranging from 29° to 32° F. Gives results of sulfur fumigation in storage.

Evans, I. B. P.

1910 The New York apple tree canker or black rot fungus in South Africa. Transvaal agr. journ. 7:62–64, pl. 7.

Calls attention of South African growers to the presence of "another imported fungus, and one which it will not be well to neglect."

Faurot, F. W.

1903 Black rot. *In* Report of fungous diseases occurring on cultivated fruits during the season of 1902. Missouri State Fruit Exp. Sta. Bul. 6:6–7.

The name *blossom rot* is employed for calyx-end infections on apples. Symptoms are described.

1912 Black rot. *In* Common orchard troubles, spray mixtures, and spray calendar. Missouri State Fruit Exp. Sta. Bul. 23: 14–15, fig. 8–9.

States that black rot, also called blossom-end rot, occurs largely on fruits of which the skin has been broken, and that owing to the habits of the fungus it is not controlled by spraying.

Floyd, Bayard F.

1905 Apple canker. Black rot. *In* Some common fungous diseases and their treatment. Missouri State Hort. Soc. Ann. rept. 48:432.

Notes that windfall apples are very susceptible.

Freeman, E. M.

1905 Black rot of apple (Sphaeropsis Malorum Peck). *In* Minnesota plant diseases, p. 363–364, fig. 194.

Gives a short general account of black rot, leaf spot, and canker.

Fückel, L.

1869 Symbolae mycologicae, p. 1–459, pl. 1–6.

Descriptions of *Diplodia pseudodiplodia* Fckl. (p. 393) and *Diplodia Malorum* Fckl. (p. 395).

Galloway, B. T.

1892 Report on the experiments made in 1891 in the treatment of plant diseases. U. S. Agr. Dept., Veg. Path. Div. Bul. 3:1–76. Illustrated.

Gives (p. 39) an account of petal and young fruit infection induced by *Sphaeropsis Malorum*.

Garman, H.

1895 Spraying experiments in 1895. Kentucky Agr. Exp. Sta. Bul. 59:111–129. Illustrated.

Sphaeropsis Malorum said (p. 127) to be the cause of most of the fruit rot in the State.

1908 Brown rot of apples. *In* 1. Spraying apple trees. 2. Apple orchard pests in Kentucky. Kentucky Agr. Exp. Sta. Bul. 133:8, 65–66.

The disease on apple fruit (due to *Sphaeropsis Malorum*) is called brown rot, and spraying experiments for the control of the disease are reported.

Giddings, N. J.

1908 Apple canker. *In* The occurrence of plant diseases in 1907. Vermont Agr. Exp. Sta. Ann. rept. **20**:331.

Apple canker, caused by *Sphaeropsis Malorum*, said to be rather prevalent in some orchards. The statement is made that the disease is easily controlled by pruning and spraying, and is thus kept down in most well-tended orchards.

Green, W. J., Selby, A. D., and Gossard, H. A.

1915 Spraying program for orchards with combinations recommended. Ohio Agr. Exp. Sta. Circ. 149:53–60.

Suggest (p. 54–55) a combination of insecticide and fungicide for control of codling moth, apple scab, and black rot.

Griffon, E., and Maublanc, A.

1910 Sur des espèces de Sphaeropsis et de Diplodia parasites du poirier et du pommier. Soc. Myc. France. Bul. **26**:307–316. Illustrated.

Discuss symptoms, and several species of fungi on apple and pear. The conclusion is reached that these trees may be attacked by Sphaeropsis and Diplodia, which act as wound parasites. The species involved are regarded as distinct and are briefly described; these are *Sphaeropsis Malorum* Peck, *Sphaeropsis pseudodiplodia* (Fckl.) Del., and an undetermined Diplodia.

Güssow, H. T.

1911 Black rot (Sphaeropsis Malorum Peck.). *In* Report of the Dominion Botanist. Experimental Farms (Canada). Rept. **1911**:246–247.

Discusses symptoms and control.

Halsted, B. D.

1892 The black rot of the quince. *In* Some fungous diseases of the quince fruit. New Jersey Agr. Coll. Exp. Sta. Bul. 91:8–10, fig. 5–6.

Concludes from observation and experiment that the species of Sphaeropsis on quince, apple, and pear are the same. States that the fungus causes one of the most destructive decays of the quince, and that the spores pass through the air or are carried by insects.

1894 Decays of mature apples. *In* Report of the Botanist. New Jersey Agr. Exp. Sta. Ann. rept. **14**: 367–377, fig. 35–41.

Symptoms of black rot well described (p. 374–375). Author makes the point that the fungus probably gains access through remnants of the flower at the free end.

Harrison, Charles

1823 A treatise on the culture and management of fruit trees, p. 1–356. Illustrated.

Attributes (p. 341–343) canker to such causes as injudicious pruning, bruising, nailing, bad subsoil. Surgical methods recommended.

Hartig, R.

1894 Text-book of the diseases of trees, p. 1–331. (Translated by Somerville and Ward.)

Hartley, C. P.

1908 a Some apple leaf-spot fungi. Science n. s. **27**: 212.

Reports the finding of eighteen different species of fungi on apple leaf spots in West Virginia, *Sphaeropsis Malorum* being among the common ones.

1908 b Some apple leaf-spot fungi. Science n. s. **28**: 157–159.

Gives brief historical review of the question of the etiology of apple leaf spot. A list of several species of fungi found on spotted leaves is given, and inoculation experiments with certain of these are reported. Results indicate that *Coniothyrium pirina* is a wound parasite, while *Coryneum foliicolum* appeared to be even less parasitic.

1913 Twig canker on black birch. Phytopath. **3**: 248–249.

Reports the isolation of a Sphaeropsis, closely resembling *S. Malorum* but with somewhat smaller spores, from swollen cankered black birch twigs (*Betula lenta* L.). Inoculation experiments show that the organism is parasitic *only* under certain conditions, nor is it regarded as the cause of the swollen cankers.

Heald, F. D.

1906 The black-rot of apples due to Sclerotinia fructigena. Nebraska Agr. Exp. Sta. Ann. rept. **19**: 82–91. Illustrated. (See also p. 22, 61.)

Points out that the term *black rot* is a confused one, having been used for diseases caused by both Monilia and Sphaeropsis. The two diseases are compared and contrasted as to symptoms.

Hedges, Florence, and Tenny, L. S.

1912 A knot of citrus trees caused by Sphaeropsis tumefaciens. U. S. Plant Indus. Bur. Bul. 247: 1–74. Illustrated.

Hesler, L. R.

1912 The New York apple tree canker. Indiana Acad. Sci. Proc. **1911**: 325–339, fig. 1–7.

Gives data concerning the geographical distribution, importance, symptoms, etiology, and control of the disease. The synonymy of the fungus is reviewed.

1913 Physalospora Cydoniae. Phytopath. **3**: 290–295. Illustrated.

Proves experimentally the genetic connection between *Physalospora Cydoniae* and *Sphaeropsis Malorum.*

1914 Biological strains of Sphaeropsis Malorum. Phytopath. **4**: 45.

Results of cross-inoculation work with the fungus from several host plants indicate that there is one large morphological species embracing many biological races.

Hewitt, J. L., and Hayhurst, P.

1911 Diseases of apple trees and fruit caused by fungi and insects. Arkansas Agr. Exp. Sta. Bul. 109: 409–445.

Note the occurrence of black rot and leaf spot in Arkansas (p. 438, 440–441).

Howitt, I. E.

1913 Fungus diseases. Ontario Agr. Coll. and Exp. Farm. Ann. rept. **38**: 29–30.

Notes the occurrence of black rot canker along with other plant diseases.

Ingram, Della

1912 Preliminary notes on a twig blight of Quercus prinus. Phytopath. **2**: 96–97.

Mentions an apparently serious disease of the chestnut oak which occurs in Connecticut, Virginia, Maryland, and Pennsylvania. The organism associated with the disease is said to agree with *Dothiorella quercina* (C. & Ell.). (Cf. Rankin, W. H., 1914, p. 141.)

Jehle, R. A.

1913 The brown rot canker of the peach. Phytopath. **3**: 105–110, pl. 10, fig. 1–5.

Reports successful use of coal tar on wounds of peaches.

Jones, L. R., and Giddings, N. J.

1907 Apple canker. *In* The occurrence of plant diseases in Vermont in 1906. Vermont Agr. Exp. Sta. Ann. rept. **19**: 231–232.

The fungus *Sphaeropsis Malorum* said to continue its destructive invasion and to be the cause of every case of apple canker examined.

Kern, F. D.

1906 Indiana plant diseases in 1905. Purdue Univ. Agr. Exp. Sta. Bul. 111: 121–134.

Black rot of the apple, pear, and quince reported (p. 125) from the southern part of the State only.

1907 Indiana plant diseases in 1906. Purdue Univ. Agr. Exp. Sta. Bul. 119: 425–436.

Mentions (p. 428) black rot and canker of the apple, and black rot of quince, present to some extent in the southern part of the State.

Kinney, L. F.

1895 a Some special orchard treatment of the apple, pear, and quince. Rhode Island Agr. Exp. Sta. Bul. 31: 1–17, fig. 1–9.

Reports (p. 10) failure to control black rot of quince by spraying.

1895 b The leaf spot of the apple and pear. *In* Horticultural Division. Rhode Island Agr. Exp. Sta. Ann. rept. **7**: 188–189, fig. 7–8.

Points out resemblance of injury by apple leaf miner (*Tischeria malifoliella* Clemens) to apple leaf spot. Spots on the leaves, and spores of *Phyllosticta pirina*, which is regarded as the cause, are figured.

1895 c The brown rot. *In* Horticultural Division. Rhode Island Agr. Exp. Sta. Ann. rept. **7**: 192–193, fig. 12.

Symptoms are given. The disease on the fruit (which author calls brown rot) and spores of the fungus are figured.

Kirchner, Oskar

1906 Die Krankheiten und Beschädigungen unserer landwirtschaftlichen Kulturpflanzen, p. 1–647.

States (p. 440) that the canker disease of apple trees, caused by *Diplodia pseudodiplodia* Thüm., occurs in North America, France, and perhaps Germany.

Lamson, H. H.

1897 Department of Bacteriology. *In* Ninth annual report. New Hampshire Coll. Agr. Exp. Sta. Bul. 48: 146–147.

Bordeaux mixture said to have had little effect in controlling leaf spot due to *Phyllosticta pirina;* hence work was directed toward its control.

1899 Apple diseases. *In* Notes on apple and potato diseases. New Hampshire Coll. Agr. Exp. Sta. Bul. 65: 106–107, fig. 38–39.

Notes the serious nature of leaf spot, which is said to be caused partly at least by *Phyllosticta pirina.*

1901 Apple tree canker. *In* Thirteenth annual report. New Hampshire Coll. Agr. Exp. Sta. Bul. 87: 130.

Reports the presence of a canker which is believed to be caused by a fungus.

1902 The cold storage of apples.— Part II. Influence of cold storage on the decay of apples. Effect of wrapping apples in paper. New Hampshire Coll. Agr. Exp. Sta. Bul. 93: 75–81, fig. 1.

Sphaeropsis Malorum listed (p. 75) as one of three fungi which cause most of the rotting. Author concludes (p. 81) that a temperature of 34° F. is more effective than 40° to 45° F., and that wrapping the fruit is of decided advantage in extending the keeping period beyond the first of June. Clean newspaper said (p. 81) to be just as effective as more expensive paper.

1903 Leaf spot. *In* Fungous diseases and spraying. New Hampshire Coll. Agr. Exp. Sta. Bul. 101: 61–62. Illustrated.

Bordeaux mixture said to have little effect in controlling leaf spot of apple.

Lewis, C. E.

1909 Apple diseases caused by Coryneum foliicolum and Phoma Mali. Maine Agr. Exp. Sta. Bul. 170: 183–200, fig. 17–42.

Reports successful infection experiments with *Sphaeropsis Malorum* Peck on injured bark and on uninjured apple leaves.

1912 Inoculation experiments with fungi associated with apple leaf spot and canker. Phytopath. **2**: 49–62.

An account of experiments directed toward the determination of the parasitism of such fungi as *Sphaeropsis Malorum, Phyllosticta limitata* Peck, *Coniothyrium pirina* (Sacc.) Sheldon, and *Coryneum foliicolum* Fckl. Author concludes that a part of the leaf spot in Maine is due to *Sphaeropsis Malorum,* but that a similar spotting is due to bordeaux mixture; that *Sphaeropsis Malorum* is the only fungus isolated from apple leaves in the State which causes spots when inoculations are made from pure cultures; and that, of the several fungi studied, this fungus does the greatest damage to branches and to twigs.

Lewis, I. M.

1908 Apple leaf spot. New Hampshire Agr. Exp. Sta. Ann. rept. **19–20**: 365–369, pl. 8–9.

Gives a historical review of the causal nature of the disease, and presents inoculation and control data.

Lochhead, William

1905 Black rot canker. Ontario Agr. Coll. and Exp. Farm. Ann. rept. **30**: 49, fig. 4–5.

Defines the term *canker* and outlines control measures.

1909 Apple diseases. *In* Fungous diseases in Quebec in 1908. Quebec Soc. Prot. Plants from Ins. and Fung. Dis. Ann. rept. **1**: 31.

The prevalence of the canker form of this disease is noted.

Longyear, B. O.

1904 Fungous diseases of fruits in Michigan. Michigan State Agr. Coll. Exp. Sta. Spec. bul. 25: 1–68, fig. 1–42.

Records the black rot disease of apple (p. 10–13), pear (p. 16), and quince (p. 20).

Lunge, George

1909 Coal tar and ammonia, Part I, chap. 1, p. 1–15.

Notes differences in tars, both physical and chemical, depending on the origin. Tar obtained from the same material also differs very much in composition, according to the temperature of the dry distillation, and even according to the shape of the retorts.

McAlpine, D.

1902 Fungus diseases of stone-fruit trees in Australia and their treatment, p. 1–165. Illustrated.

Lists (p. 133, 134) *Diplodia Malorum* on peach and plum twigs.

M'Cormack, Edna F.

1910 Black rot of the apple. *In* Fungous diseases of the apple. Indiana State Entomologist. Rept. **3**: 142–144. Illustrated.

Symptoms discussed.

McCready, S. B.

1910 Black rot canker (Sphaeropsis Malorum Peck). Ontario Agr. Coll. and Exp. Farm. Ann. rept. **35**: 41–42.

Brief reference to hosts, distribution, etiology, and control.

1911 Black rot of apple. Ontario Agr. Coll. and Exp. Farm. Ann. rept. **36**: 37.

Reports use of lead paint and gas tar as wound dressings; the latter found to give better protection.

Mangin, L.

1901 Sur une nouvelle maladie des pommiers causée par le " Diplodia pseudo-diplodia." Journ. agr. prat. n. s. **2**: 138–139.

Reports occurrence of the disease on apple branches in France, and gives suggestions for control.

Morse, W. J.

1909 Notes on plant diseases, 1908. Maine Agr. Exp. Sta. Bul. 164: 1–28. Illustrated.

States (p. 3–4) that *Sphaeropsis Malorum* from leaf spot produced decay of fruit as a result of artificial inoculation. States (p. 10) that self-boiled lime-sulfur seemed effective in controlling leaf spot.

Morse, W. J., and Lewis, C. E.

1910 Maine apple diseases. Maine Agr. Exp. Sta. Bul. 185:335–392. Illustrated.

Notes on the etiology of leaf spot and canker. Canker fungus in Maine orchards follows frost injury.

Munson, W. M.

1909 Apple enemies, and how to fight them. West Virginia Univ. Agr. Exp. Sta. Bul. 121:353–366.

Control measures for leaf spot and canker given (p. 360–362).

Norton, J. B. S., and Symons, T. B.

1907 Black-rot (Sphaeropsis Malorum). *In* Control of insect pests and diseases of Maryland crops. Maryland Agr. Exp. Sta. Bul. 115:178.

Give brief recommendations for the control of black rot, leaf spot, and canker.

O'Gara, P. J.

1902 Notes on canker and black-rot. Science n. s. **16**: 434–435.

Notes a case of girdling of branches of sumac (*Rhus glabra* L.) by *Sphaeropsis rhoina* (Schw.) Starb., which fungus, after careful cultural and inoculation experiments, is regarded as probably identical with *Sphaeropsis Malorum*.

Orton, C. R.

1914 Black rot. *In* Some orchard diseases and their treatment. Pennsylvania State Hort. Assoc. Proc. **55**: 43–56. Illustrated.

Author states that *Sphaeropsis Malorum* rarely if ever produces cankers on its own initiative. He notes its wide occurrence on various plants, and says that a perfect stage has recently been found on apple, quince, oak, grape, witch-hazel, and other hosts.

Orton, W. A.

1902–1907 Plant diseases in the United States in 1901–1907. U. S. Agr. Dept. Yearbook **1901**:669; **1902**:715; **1903**:550; **1904**:582–583; **1905**:603–604; **1906**:499–500; **1907**: 577–579.

Gives notes on the occurrence and destructiveness of black rot, leaf spot, and canker of apple, pear, and quince.

Paddock, Wendell

1898 a An apple canker. Science n. s. **8**: 595–596.

Reports preliminary experiments in canker investigation. Cultures of fungi from cankers showed *Schizophyllum commune*, and a dark-spored fungus which is said to resemble *Sphaeropsis Malorum* Peck.

1898 b Additional notes on an apple canker. Science n. s. **8**: 836–837.

Suggests that *Sphaeropsis Malorum* Peck is parasitic on the wood of pear and quince as well as on that of apple. Cross-inoculations of the fruits of these three plants gave positive results.

1899 a An apple canker. Western New York Hort. Soc. Proc. **44**: 58–63. Illustrated.

(See 1899 b, of which this is a popular presentation.)

1899 b The New York apple-tree canker. New York (Geneva) Agr. Exp. Sta. Bul. 163:177–206, pl. 1–6.

Contains an account of host relationships, names of the disease, symptoms, etiology, and control. Presents conclusive data proving that *Sphaeropsis Malorum* is the cause of canker on apple; considerable data indicate that this species of Sphaeropsis also occurs on many other plants.

1900 The New York apple-tree canker (Second report). New York (Geneva) Agr. Exp. Sta. Bul. 185:203–213, pl. 1–4.

States that *Sphaeropsis Malorum* occurs on apple, pear, and quince fruits, and on apple, pear, and hawthorn trees; and that it probably occurs on several other plants, but experiments are not regarded as warranting this as a definite conclusion. Notes that apple leaves are occasionally attacked by a Sphaeropsis.

Parkinson, John

1629 Paradisi in sole paradisus terrestris, p. 1–612. Illustrated.

Briefly outlines (p. 550) the nature and control of canker. Of historical importance.

Parrot, P. J., and Fulton, B. B.

1913 Notes on tree crickets. Journ. econ. ent. 6:177–180. Illustrated.

Note that the penetration of apple bark tissues by the ovipositor of the tree cricket is apparently attended by an infection of some unknown fungus or bacterium, which results in the formation of a canker indistinguishable in its appearance and effects from the New York apple tree canker or the fire blight canker.

1914 Tree crickets injurious to orchard and garden fruits. New York (Geneva) Agr. Exp. Sta. Bul. 388:415–461. Illustrated.

Authors note (p. 442) that injuries by tree crickets are followed by some infectious agent, and that these lesions, in their external appearances and their effects, resemble superficially certain stages of the New York apple tree canker caused by *Sphaeropsis Malorum.*

Peck, C. H.

1879 Report of the Botanist. New York State Mus. Nat. Hist. Ann. rept. 31:19–60.

Reports (p. 20–21) the discovery of *Sphaeropsis Malorum* on apple fruits in Schoharie County.

1881 Report of the Botanist. New York State Mus. Nat. Hist. Ann. rept. 34:24–58, pl. 1–4.

Describes (p. 36) symptoms of black rot, and points out the fact that the distinction between Sphaeropsis and Diplodia sometimes fails, since both one- and two-celled spores are found in the same spore case.

Pollock, J. B., and Kauffman, C. H.

1905 Michigan fungi. Michigan Acad. Sci. Rept. 7:57–67.

List *Sphaeropsis Mali* (West.) Sacc. and *S. Malorum* Peck.

Potebnia, A.

1907 Mycologische Studien. Ann. myc. 5:1–28, pl. 1–3, fig. 1–43.

Discusses mycelial development, including spore germination and protoplasmic streaming.

1910 Beiträge zur Micromycetenflora Mittel-Ruszlands. Ann. myc. 8:42–93, fig. 1–38.

States that the pycnidia of *S. pseudodiplodia* (Fckl.) Del. arise meristogenetically.

1912 Pilzliche Symbionten. 2. Sphaeropsis und Helicomyces, p. 28. Illustrated. (Separate sent by Potebnia to the writer.)

Price, H. L.

1909 Black rot. *In* Fighting the insect pests and diseases of orchard, field, and garden crops. Virginia Agr. Exp. Sta. Circ. 7:10–11, fig. 2.

Recommendations for the control of black rot, leaf spot, and canker.

Quaintance, A. L., and Scott, W. M.

1912 Apple leaf-spot. *In* The more important insect and fungous enemies of the fruit and foliage of the apple. U. S. Agr. Dept. Farmers' bul. 492:35–36, fig. 20.

Discuss the importance, symptoms, etiology, and control of apple leaf spot caused by *Sphaeropsis Malorum*.

Rankin, W. H.

1914 Sphaeropsis canker of Quercus prinus. Phytopath. 4:44–45.

Reports *Sphaeropsis Malorum* Berk. as causing twig and limb cankers on chestnut oak (*Quercus prinus* L.), the account being based on observation and inoculation experiments. Regards the disease as the one described by Miss Della Ingram in Phytopathology **2**:96 (p. 136).

Reddick, Donald

1912 Frost injury. New York State Fruit Growers' Assoc. Proc. **11**:34–41, fig. 1–2.

Sphaeropsis Malorum said to be usually found following frost injury.

Reed, H. S.

1908 Fall blossoming of the apple induced by the black rot. Plant world **11**:256–257.

Notes a case in which *Sphaeropsis Malorum* inhibited the normal activities of an apple tree, allowing the tissues to carry on the growth which would normally have been deferred for several months, and resulting in the unfolding of normal blossoms on October 5.

Reed, H. S., and Cooley, J. S.

1911 Black rot (Sphaeropsis Malorum). *In* Plant diseases in Virginia in the years 1909 and 1910. Virginia (Polytech. Inst.) Agr. Exp. Sta. Ann. rept. **1909–1910**: 102–103, fig. 21.

Record black rot, leaf spot, and canker. Report pycnospores discharging from pycnidia on leaves at Blacksburg on June 25, 1910.

Reed, H. S., Cooley, J. S., and Rogers, J. T.

1912 Foliage diseases of the apple. Virginia (Polytech. Inst.) Agr. Exp. Sta. Bul. 195:1–24, fig. 1–13.

Give points concerning the varietal susceptibility of apples; the distribution, importance, and symptoms of the disease; and the life history of the fungus.

Reed, H. S., and Crabill, C. H.

1913 Black rot (Sphaeropsis Malorum). *In* Plant diseases in Virginia in the years 1911 and 1912. Virginia (Polytech. Inst.) Agr. Exp. Sta. Ann. rept. **1911–1912**: 36, fig. 3.

Note that *Sphaeropsis Malorum* occurs on twigs previously killed by the fire blight organism. Figure a multilocular sterile (?) pycnidium.

Reed, H. S., and Stahl, H. S.

1911 The erepsins of Glomerella rufomaculans and Sphaeropsis Malorum. Journ. biol. chem. **10**: 109–112.

Authors find evidence of erepsin produced in pure cultures.

Roberts, J. W.

1913 The "rough-bark" disease of the Yellow Newtown apple. U. S. Plant Indus. Bur. Bul. 280:1–15, pl. 1–3.

Reports (p. 9, 15) *Phomopsis Mali*, a new species, associated with *Sphaeropsis Malorum* on leaf spots.

1914 Experiments with apple leaf-spot fungi. Journ. agr. research 2: 57–66, pl. 7, fig. 1–3.

Reports the isolation of several species, including *Sphaeropsis Malorum*, from apple leaf spots. A new species, *Alternaria Mali*, is in the list and is technically described. From experiments conducted it is concluded that this species may be classed as a rather strong facultative parasite.

Rose, D. H.

1914 Ring rot. *Also*, Black rot (Sphaeropsis Malorum). *In* Biennial report. Missouri State Fruit Exp. Sta. Bul. 24 (Bienn. rept. 1913–1914): 20, 23–24, pl. 5, fig. 1–2.

Ring rot, or blossom-end rot, of the apple fruit thought to be due to frost injury at blossoming time, followed by *Sphaeropsis Malorum* Peck. Author gives notes on the destructiveness of black rot.

Ruggles, A. G., and Stakman, E. C.

1911 Black rot *In* Orchard and garden spraying. Minnesota Univ. Agr. Exp. Sta. Bul. 121: 15.

Symptoms of black rot given.

Saccardo, P. A.

1884 a Phoma Malorum (Berk.) Sacc. Syll. Fung. 3: 152–153.

A technical Latin description is given. Author lists *Sphaeropsis Malorum* Berk. in synonymy.

1884 b Sphaeropsis Malorum Peck. Syll. Fung. 3: 294.

Describes the fungus which Peck (1881) reports and regards as new, thus giving rise to the name *Sphaeropsis Malorum* Peck.

Salmon, E. S.

1907 Apple leaf-spots. Gard. chron. ser. 3: 42: 305–306, fig. 120–124.

A brief discussion of varietal susceptibility and etiology of leaf spots caused by a species of Phyllosticta and one of Sphaeropsis. The author is in doubt as to whether the latter species is *S. Malorum*.

Scott, W. M.

1906 The control of apple bitter-rot. U. S. Plant Indus. Bur. Bul. 93: 1–36, pl. 1–8.

Gives (p. 27–33) results of experiments for the control of leaf spot in connection with apple scab, sooty blotch, and bitter rot.

1908 Apple leaf-spot. *In* Self-boiled lime-sulphur mixture as a promising fungicide. U. S. Plant Indus. Bur. Circ. 1: 12.

States that it appears that leaf spot may be prevented by this fungicide, but no data are cited.

1912 Apple leaf-spot, or frog-eye. *In* Spraying to control the important insects and fungous diseases affecting the fruit and foliage of the apple. Thomsen Chemical Co. (Baltimore, Md.). Circ. 4: 14–15, pl. 2, fig. 1.

Scott, W. M., and Quaintance, A. L.

1907 Leaf-spot diseases. *In* Spraying for apple diseases and the codling moth in the Ozarks. U. S. Agr. Dept. Farmers' bul. 283: 18–20, fig. 3.

Authors give recommendations for the control of leaf spot, which, as they state, may be due to *Sphaeropsis Malorum*.

Scott, W. M., and Rorer, J. B.

1908 Apple leaf-spot caused by Sphaeropsis Malorum. U. S. Plant Indus. Bur. Bul. 121:45–54, pl. 3–4.

Authors discuss the common names of the leaf spot, its history, geographical occurrence, importance, symptoms, etiology, and control. Proof of the pathogenicity of *Sphaeropsis Malorum* on apple leaves is given, together with a study of the rôle of associated fungi on leaf spots.

1909 Apple blotch, a serious disease of Southern orchards. U. S. Plant Indus. Bur. Bul. 144:1–28, pl. 1–6.

Authors suggest (p. 11) that *Sphaeropsis Malorum* is a factor in the killing of apple buds Further investigation is deemed desirable.

Scribner, F. L.

1890 Black-rot of the apple. Fungus diseases of the grape and other plants and their treatment, p. 81–83, fig. 1606.

Descriptions of the disease and of the fungus, called *Macrophoma Malorum*, are given.

Seaver, F. J.

1908 Color variation in some of the fungi. Bul. Torrey Bot. Club 35:307–314.

Points out that color characters are misleading and misused in the Hypocreales.

Selby, A. D.

1900 A condensed handbook of the diseases of cultivated plants in Ohio. Ohio Agr. Exp. Sta. Bul. 121:1–69, fig. 1–54.

Notes (p. 14) the disease on the leaves and fruit of apple and quince.

1910 Black-rot. *In* A brief handbook of the diseases of cultivated plants in Ohio. Ohio Agr. Exp. Sta. Bul. 214:368–369, 436, fig. 1–105.

Notes the importance of the disease in Ohio.

1913 Disease susceptibility of apple varieties in Ohio. Ohio Agr. Exp. Sta. Circ. 133:53–56.

Indicates degree of susceptibility of apple varieties to black rot and canker.

Shear, C. L.

1910 Life history of Melanops Quercuum (Schw.) Rehm forma Vitis Sacc. Science n. s. **31**:748.

Pure cultures of ascospores of *Melanops Quercuum* (Schw.) Rehm forma *Vitis* Sacc. [= *Botryosphaeria Berengeriana* de Not. = *B. fuliginosa* (M. & N.) E. & E.] said to produce a pycnidial form which agrees with *Sphaeropsis Malorum* Berk. and *Diplodia pseudodiplodia* Fckl.

1913 Some observations on phytopathological problems in Europe and America. Phytopath. **3**:77–87.

Sphaeropsis Malorum reported (p. 81–82) as doing no noticeable injury in orchards from Italy to England.

1914 Life history of Sphaeropsis Malorum Berk. Phytopath. **4**:48–49.

Concludes from cultural studies the ascosporic form of *Sphaeropsis Malorum* Berk. is *Melanops Quercuum* f. *Vitis*.

Shear, C. L., and Wood, Anna K.

1913 Studies of fungous parasites belonging to the genus Glomerella. U. S. Plant Indus. Bur. Bul. 252:1–110. Illustrated.

Discuss host relationships, variability, and parasitism of Glomerella.

Sheldon, J. L.

1905 A report on plant diseases of the State. West Virginia Univ. Agr. Exp. Sta. Bul. 96:69–99. Illustrated.

Black rot (p. 74), leaf spot (p. 74–75), and canker (p. 74) reported.

1907 The taxonomy of a leaf-spot fungus of the apple and other fruit-trees. Torreya **7**: 142–143.

The name of the leaf spot, or frog-eye, organism is changed from *Phyllosticta pirina* Sacc. to *Coniothyrium pirina* (Sacc.) Sheldon.

1908 Another leaf-spot fungus of the apple. Torreya **8**: 139–141.

Illosporium malifoliorum n. sp. is said to be concerned with the leaf spot, in a secondary manner. This fungus is described.

Smith, R. I., and Stevens, F. L.

1910 Leaf spot. *Also*, Black rot. *In* Insects and fungous diseases of apple and pear. North Carolina Agr. Exp. Sta. Bul. 206: 94, 95, 102–103, fig. 23.

Call the disease *Sphaeropsose*, and state that perhaps one, but probably several, species are responsible for leaf spot.

Stene, A. E.

1910 Some suggestions for Rhode Island apple growers. Rhode Island State Agr. Bd. Ann. rept. **25**: 93–181. Illustrated.

Leaf spots and canker said to be general in the State (p. 152–153).

Stevens, F. L., and Hall, J. G.

1907 Sphaeropsis on apple twigs. *In* Some apple diseases. North Carolina Agr. Exp. Sta. Bul. 196: 52–53.

1909 a Notes on plant diseases occurring in North Carolina. North Carolina Agr. Exp. Sta. Ann. rept. **31**: 66–82, fig. 1–10.

Black rot and canker reported (p. 66). Sphaeropsis and an ascomycetous fungus found; name of latter not given. Sphaeropsis reported (p. 75) as a canker-producing fungus on pear.

1909 b Variation of fungi due to environment. Bot. gaz. **48**: 1–30, fig. 1–37. *See also* North Carolina Agr. Exp. Sta. Ann. rept. **32** (1908–1909): 47–71, fig. 1–37.

Authors discuss observations on the influence of environment on the characters of certain fungi.

Stevens, F. L., and Sherman, F.

1903 The black rot. *Also*, The black rot of the quince. *In* Insect and fungus enemies of the apple, pear, and quince, with methods of treatment. North Carolina Agr. Exp. Sta. Bul. 183: 72, 82, fig. 1–22.

Symptoms and control measures of black rot and canker given.

Stewart, F. C.

1896 A new leaf-spot disease of apples. *In* Report of the Mycologist. New York (Geneva) Agr. Exp. Sta. Ann. rept. **14** (1895): 545–546.

Records *Phyllosticta limitata* n. sp. on apple leaves on Long Island. Technical description given.

1904 Apple canker. *In* Fungi and fungous diseases. Western New York Hort. Soc. Proc. **49**: 53.

States that spraying for apple canker caused by *Sphaeropsis Malorum* is only a partial preventive; a matter not understood.

1909 Apple leaf spot. *In* Recent investigations on plant diseases. Western New York Hort. Soc. Proc. **54**: 78–79.

Believes that the leaf spot problem in New York is not completely solved. Points out that spraying often fails to control.

1910 Notes on New York plant diseases, I. New York (Geneva) Agr. Exp. Sta. Bul. 328:303–404, pl. 1–18.

Discusses (p. 312–313) occurrence of leaf spot in New York. Gives (p. 323–324) an account of a peculiar disease of the trunk of Walbridge apples and suggests that *Sphaeropsis Malorum* may have been a factor in producing the same. Suspects (p. 377–379) that the fungus also causes the failure of grafts of the pear.

Stewart, F. C., and Blodgett, F. H.

1899 A fruit-disease survey of the Hudson Valley in 1899. New York (Geneva) Agr. Exp. Sta. Bul. 167:273–308, pl. 1–4.

Notes on the geographical occurrence of the leaf spot and canker in the Hudson Valley (p. 283, 284, 301–302).

Stewart, F. C., and Eustace, H. J.

1902 Two unusual troubles of apple foliage. New York (Geneva) Agr. Exp. Sta. Bul. 220:215–233, pl. 1–5.

Authors conclude that spray material caused spotting of apple foliage; suspect the parasitism of Phyllosticta; suggest that drops of rain may act as lenses and concentrate the sun's rays, overheating the tissue beneath.

Stewart, F. C., Rolfs, F. M., and Hall, F. H.

1900 A fruit-disease survey of western New York in 1900. New York (Geneva) Agr. Exp. Sta. Bul. 191:289–331, pl. 1–6.

Note geographical occurrence of the disease in western New York.

Stone, G. E.

1914 Lime and sulfur solutions. Massachusetts Agr. Exp. Sta. Circ. 39:1–4.

Lime and sulfur said to hold leaf spot in check, and believed to have material effect on cankers.

Stone, G. E., and Fernald, H. T.

1908 Canker. *In* Fungicides, insecticides, and spraying directions. Massachusetts Agr. Exp. Sta. Bul. 123:16.

Suggestions for canker control are given.

Stone, G. E., and Monahan, N. F.

1907 The lime and sulfur mixture as a fungicide. *In* Report of the Botanist. Massachusetts (Hatch) Agr. Exp. Sta. Ann. rept. **19**: 167.

State that observations seem to indicate that spraying with lime and sulfur succeeds to some extent in controlling canker.

Stone, G. E., and Smith, R. E.

1903 Apple-leaf spot. *In* Report of the Botanists. Massachusetts (Hatch) Agr. Exp. Sta. Ann. rept. **15**: 27, 32–34.

Frost followed by cold wet weather caused apple leaf spot.

Sturgis, W. C.

1893 a Black-rot (Sphaeropsis Malorum Peck). *In* Common fungous diseases and their treatment. Connecticut (New Haven) Agr. Exp. Sta. Bul. 115:6–7.

Black rot of apple, quince, and pear noted.

1893 b Black rot of quinces. *In* Report of the Mycologist. Connecticut (New Haven) Agr. Exp. Sta. Ann. rept. **1892**: 43–44.

Description of black rot disease of quince fruits.

1894 Black rot (Sphaeropsis Malorum Peck). *In* Report of the Mycologist. Connecticut (New Haven) Agr. Exp. Sta. Ann. rept. **17**: 78–79.

Reports inoculation and spore germination data. States that the wind and other agencies carry the fungus spores.

Taft, L. R., and Davis, G. C.

1895 Black rot (Sphaeropsis Malorum Berk.). *In* The pests of the orchard and garden. Michigan State Agr. Coll. Exp. Sta. Bul. 121:21.

Briefly describe black rot and give suggestions for control.

Taubenhaus, J. J.

1912 A further study of some Gloeosporiums and their relation to a sweet pea disease. Phytopath. **2**: 153–160, pl. 16, fig. 1–19.

States (p. 157) in a footnote that black rot was very prevalent in the very dry summer of 1911.

Taylor, W. A.

1914 Fruit diseases. *In* Report of the Chief of the Bureau of Plant Industry. U. S. Agr. Dept. Rept. **1913**: 105–133.

States (p. 107) that a variety of *Melanops Quercuum* has been shown to be the perfect stage of *Sphaeropsis Malorum*.

Thümen, F. von

1879 Fungi pomicoli, p. 108. (Cited from Baccarini, 1890.)

Waite, M. B.

1898 a An apple canker. Western New York Hort. Soc. Proc. 43: 9–11.

Briefly outlines the history and distribution of the disease, and suggests that the cause may be *Schizophyllum commune*. Control measures suggested.

1898 b An apple canker. Rural New-Yorker **57**: 82, fig. 32.

Essentially the same paper as the preceding.

1906 Fungicides and their use in preventing diseases of fruits. U. S. Agr. Dept. Farmers' bul. 243: 1–32, fig. 1–17.

Brief notes (p. 19) on control of black rot, leaf spot, and canker.

1908 Apple leaf blight. *In* Diseases of orchard trees and fruits. Pennsylvania Agr. Dept. Ann. rept. **13**: 450–452.

Gives treatment for leaf spot.

1910 Experiments on the apple with some new and little-known fungicides. U. S. Plant Indus. Bur. Circ. 58: 1–19.

Notes on leaf spot.

Walker, Leva B.

1908 A new form of Sphaeropsis on apples. Nebraska Agr. Exp. Sta. Ann. rept. **21**: 34–44, fig. 1–10.

Compares typical *Sphaeropsis Malorum* with a new form, the latter having larger spores, pycnidia with long necks, and no ostiole, and being more virulent in producing black rot.

Wallace, Errett

1913 Scab disease of apples. Cornell Univ. Agr. Exp. Sta. Bul. 335: 541–624. Illustrated.

Warren, G. F., and McCourt, W. E.

1905 The apple-tree canker. *In* An apple orchard survey of Wayne County, New York. Cornell Univ. Agr. Exp. Sta. Bul. 226: 341–345, fig. 86–87.

Attention is given to the economic importance of the canker and to control measures followed by the growers in this section of the country. It is said that very few mature Twenty Ounce trees are not badly cankered, and Esopus suffers seriously.

Whetzel, H. H.

1906 The blight canker of apple and pear trees. Western New York Hort. Soc. Proc. **51**: 36–45.

Compares fire-blight and New York apple-tree cankers.

1907 The New York apple tree canker. *In* Fighting the fungi in their winter quarters. Cornell reading-course for farmers, March, 1907, p. 670–671, fig. 365.

Gives symptoms of canker and measures for its control.

Whetzel, H. H., and Stewart, F. C.

1908 New York apple-tree canker. *In* Insect pests and plant diseases. IV. The control of plant diseases Cornell Univ. Agr. Exp. Sta. Bul. 252: 350, fig. 165.

Suggestions for canker control are given.

Wilcox, E. M.

1905 Black rot. *Also* Canker. *In* Diseases of the apple, cherry, peach, pear, and plum; with methods of treatment. Alabama (Auburn) Agr. Exp. Sta. Bul. 132: 89–93, pl. 2, fig. 6.

Notes on symptoms and control of black rot and canker.

Wilcox, E. M., and Stone, R. E.

1909 Black rot (Sphaeropsis Malorum). *In* Directions for the control of Nebraska plant diseases. Nebraska Agr. Exp. Sta. Ann. rept. **22**: 31.

Give schedule for control of canker and black rot.

Wilson, G. W.

1913 New York canker. *In* Notes on three limb diseases of apple. North Carolina Agr. Exp. Sta. Ann. rept. **35**: 47–49, fig. 1.

Brief summary of history, distribution, importance, and symptoms of the disease. Author states that the fungus may enter the bark under certain conditions, and that it does not travel in the wood.

Wolf, F. A.

1910 The prevalence of certain parasitic and saprophytic fungi in orchards as determined by plate cultures. Plant world 13: 190–202.

By use of trap cultures the author concludes that at no time during the period in which exposures were made (September to May) were viable spores of *Sphaeropsis Malorum* present in the atmosphere of the orchard.

1913 Control of apple black-rot. Phytopath. 3: 288–289.

Suggests that apple mummies are a source of the inoculum. Reports that in the South lime-sulfur alone is effective against the disease; bordeaux 4–4–50 also satisfactory. A spraying schedule is given.

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AGRICULTURAL EXPERIMENT STATION

THE HARD ROT DISEASE OF GLADIOLUS

L. M. MASSEY

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THE HARD ROT DISEASE OF GLADIOLUS[1]

L. M. Massey

THE HOST PLANT

The gladiolus is a cormous, summer-flowering plant. Pax (1889)[2] classifies it as a member of the family Iridaceae, of the tribe Ixioideae, subtribe Gladioleae, genus Gladiolus. The species of Gladiolus may be grown from corms, from cormels (the grayish to black, hard-shelled bodies formed on underground stems at the base of the new corm), or from seed. The plants are indigenous to South Africa, where, according to Crawford (Crawford and Van Fleet, 1911:3), about fifty species have been discovered. This writer states:

> It is also a native of middle Africa, central and southern Europe, Persia, Caucasus, and the country around the eastern end of the Mediterranean. About forty additional species have been found in these localities, and one in Hampshire, England. These have been hybridized and crossed until they are so mixed that it is impossible for the ordinary grower to say what blood may have entered a given variety — nor does it matter.

ECONOMIC IMPORTANCE OF THE GLADIOLUS INDUSTRY

According to Hendrickson (1911), there are from four hundred to five hundred acres in the United States devoted to gladioli, the annual production of corms being from 14,000,000 to 15,000,000 and the estimated value of the crops $250,000. In New York State, besides many small growers there are two growers each having over one hundred acres devoted entirely to the cultivation of gladioli. A list of the members of the American Gladiolus Society which appeared in 1914 in the *Modern Gladiolus Grower* (1:31–32) contains two hundred and twenty names, of which but sixty-three are those of amateurs and twenty-eight those of foreign dealers and growers. The output of these growers and dealers represents only a portion of the total output of the United States. Almost every florist is more or less interested in the production of corms and flowers of the gladiolus, which appears to be increasing in popularity as a cut flower.

THE DISEASE

The name *hard rot* was given to the corm stage of the disease under consideration by Wallace (1909:18), who makes no reference to a leaf stage. This name was given to distinguish the disease from other corm

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[1] Also presented to the Faculty of the Graduate School of Cornell University, January, 1916, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

Acknowledgment. The writer wishes to express his indebtedness to Professors Donald Reddick and H. H. Whetzel, under whose immediate direction the work was conducted, for helpful criticisms and suggestions.

[2] Dates in parenthesis refer to bibliography, page 180.

diseases, such as dry rot and soft rot, with which both Wallace and Fitzpatrick[3] worked prior to 1912. The writer took up the investigation of these diseases in 1912 and has given them constant study since that time.

Apparently the hard rot disease of gladiolus exists wherever gladioli are grown. Specimens have been received from many of the largest growers in the United States. Horticultural publications contain many references to corm rots, and no doubt much of this injury is due to the hard rot disease. Plants growing in the greenhouse at Cornell University from corms received from Italy by A. C. Hottes bore the leaf stage of the disease. The writer has received corms affected with hard rot from Canada, Germany, and Holland.

Prillieux and Delacroix (1894) report having studied a disease of the gladiolus in which the tissue was deeply corroded, but the writer is unable to determine whether or not it is the same disease as the one considered in this bulletin. Unpublished notes placed at the disposal of the writer by Professor F. C. Stewart, of the New York (Geneva) Agricultural Experiment Station, mention the only distinction observed, prior to Wallace's thesis (1909), between two types of rots. Concerning specimens of diseased corms received from a New York State grower, Professor Stewart suggested the probability that they were affected with the bacterial disease described by Prillieux and Delacroix, since he was unable to locate any trace of fungous hyphæ in the diseased tissue. Wallace (1909:15) was of the opinion that the corms received by Professor Stewart were affected with the hard rot disease.

In 1874 Passerini collected specimens of the leaf stage of the hard rot disease, which he contributed to exsiccatæ of Rabenhorst's *Fungi Europaei.*

Saccardo (1884) reports the occurrence of the leaf stage of the disease on *Gladiolus segetum* at Parma, Italy, and on *Gladiolus gandavensis* at Coimbra, Portugal. Allescher (1897), in addition to the occurrence on hosts listed by Saccardo, reports the disease as occurring on the leaves of *Gladiolus palustris* in Silesia. So far as known to the writer, the leaf stage of this disease has never been reported in America. A "blight" is frequently mentioned in horticultural publications, but the descriptions of the injury are in all cases so indefinite that it is impossible to determine what diseases the writers had under observation. Hicks (1907:35) and Childs (1907) write of gladiolus leaf blight, but there is nothing in their writings sufficiently definite to make it possible to determine the nature of the injury. Halsted (1894–1901) reports having worked on gladiolus diseases, but leaves the reader in doubt as to what the diseases were.

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[3] Unpublished notes of Professor H. M. Fitzpatrick, of Cornell University, covering his investigations of gladiolus diseases, were kindly placed at the disposal of the writer.

Undoubtedly the leaf stage of the hard rot disease occurs more generally throughout the country than is indicated by an examination of literature. This is due to importation of stock from Europe and exchange of stock by growers in this country. On the other hand, the writer has observed specimens of the disease on the foliage of plants grown by but three large growers.

Foliage affected with the disease was first observed by the writer in 1912 in seedling beds, and later on plants grown from cormels. Not until the season of 1915 did the writer find the disease on the foliage of large plants, at which time six plants of flowering size were observed to be affected. In many cases large flowering plants of different varieties have been observed growing in seed beds or among plants from cormels, all of which were badly diseased and yet the large plants showed no signs of the leaf stage. Large plantations of cormels have been observed in which fifty per cent of the plants bore the disease on the foliage.

Nothing has been found in literature that would indicate that there is any relation between the leaf stage and the corm stage of the disease under consideration. It has been the writer's fortune to obtain conclusive evidence that they are but different stages of the same disease, and the experimental data leading to this conclusion are here set forth.

ECONOMIC IMPORTANCE OF THE DISEASE

No figures are available to show the economic importance of the hard rot disease of the gladiolus, but it must be considerable as compared with the extent of the industry. Many thousands of corms are discarded during the winter and in the spring at planting time because of their diseased condition. During the summer many thousands of corms fail to reach maturity, due to the decay of the parent corms in the soil. While there are other diseases of the gladiolus, it is the opinion of the writer, based on observations made during the past four years, that a large proportion of this loss is due to the hard rot disease. Several varieties of gladiolus that have been examined showed fifty per cent or more of the corms to be affected by hard rot. So far as the writer knows, no variety is immune.

While the loss caused by the leaf stage of the disease is materially less than that caused by the corm stage, it is still of considerable importance to the grower. It has been observed that when the foliage of seedlings and of plants from cormels is affected by the disease, the corms are smaller than those of plantings that were free from disease. Therefore the decrease in size must be considered along with the total loss of many thousands of corms. To this must be added the extra expense incurred by the grower in sorting and selecting more or less healthy corms from diseased lots, either in filling orders or for his own planting. All in all, the loss must take from the producer a yearly toll of surprising magnitude.

SYMPTOMS

On the leaves

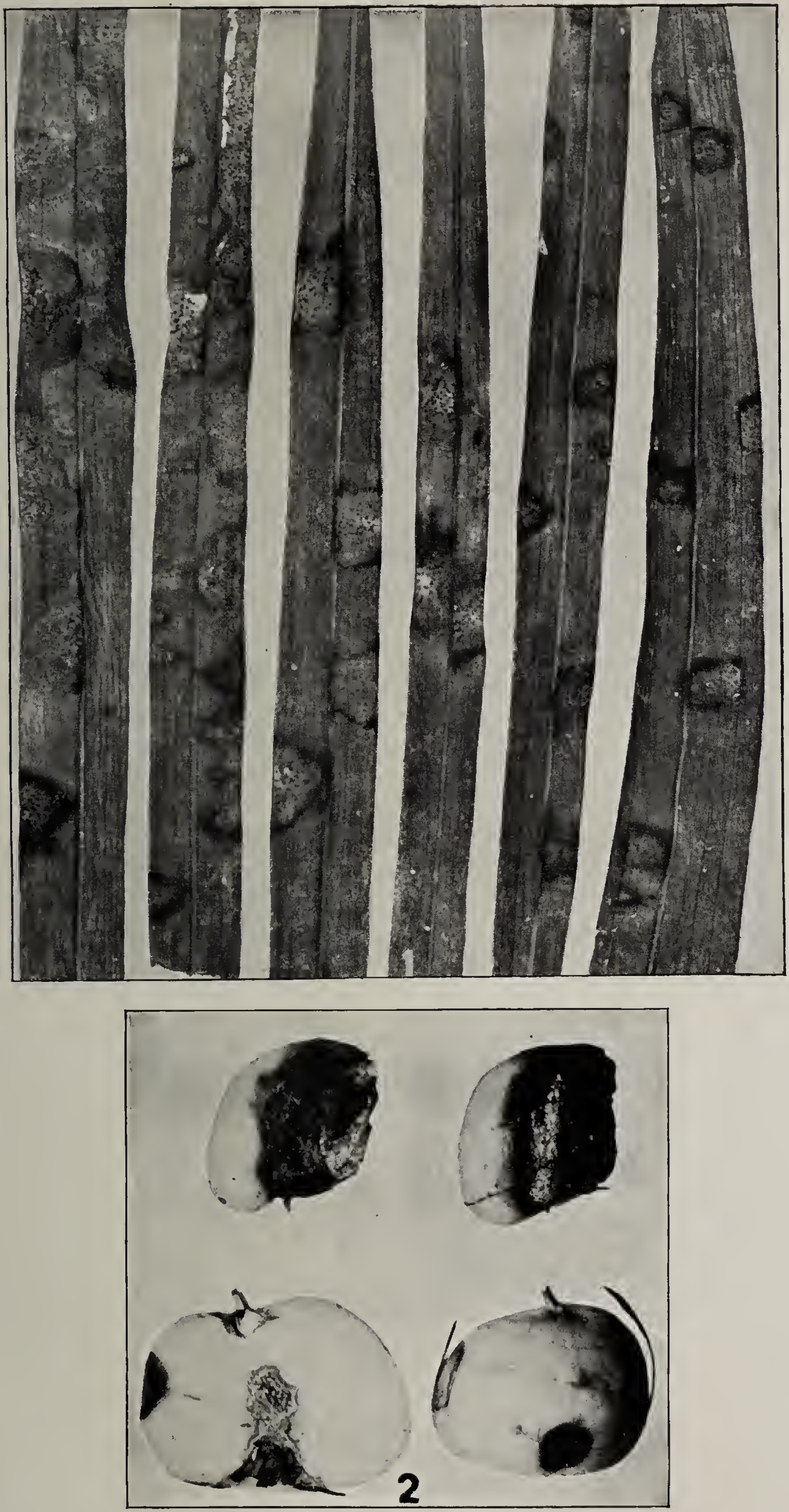
The first signs of the disease on the leaf are minute brown or purplish brown discolored areas more or less circular in outline. These lesions usually appear in July or early August. The color of the diseased areas deepens somewhat with age until a shade from reddish brown to almost black is reached. Spots of a reddish brown color predominate. In the older lesions there is a well-differentiated center, light gray in color and dotted with numerous black bodies which are very apparent (Plate xv, 1). Surrounding the center is a prominent zone, varying from purplish brown to black in color, which blends into the green of the healthy tissue.

The lesions are more or less circular but with straight sides where they are limited by the midrib and the edge of the leaf. At first the discoloration may be visible on only one side of the leaf, but it soon makes its appearance on the opposite side, so that lesions appear practically identical on either side. They are few or numerous, and vary in size depending on conditions. The coalescence of several or many spots may occur, causing the formation of a single large necrotic area along the entire side of a leaf. Lesions on the tips of the leaves are usually larger and less characteristic than those below. In some cases the ashen gray centers of diseased areas drop out, giving a shot-hole appearance. This is more likely to occur with spots on large flowering plants than with those on seedlings.

On the corms

Hard rot lesions appear in the fall as minute water-soaked spots, of a reddish brown to brownish black color, usually on the sides and the lower half of the corm but not infrequently on the upper half as well (Plate xvi). It is usually necessary to remove the husks (sheathing leaf bases) from the corms in order to see the lesions, although in some cases the husk also is diseased. The lesion on the husk serves as an indication of the more important lesion underneath. There is no sharp line of demarcation between the healthy and the diseased tissue.

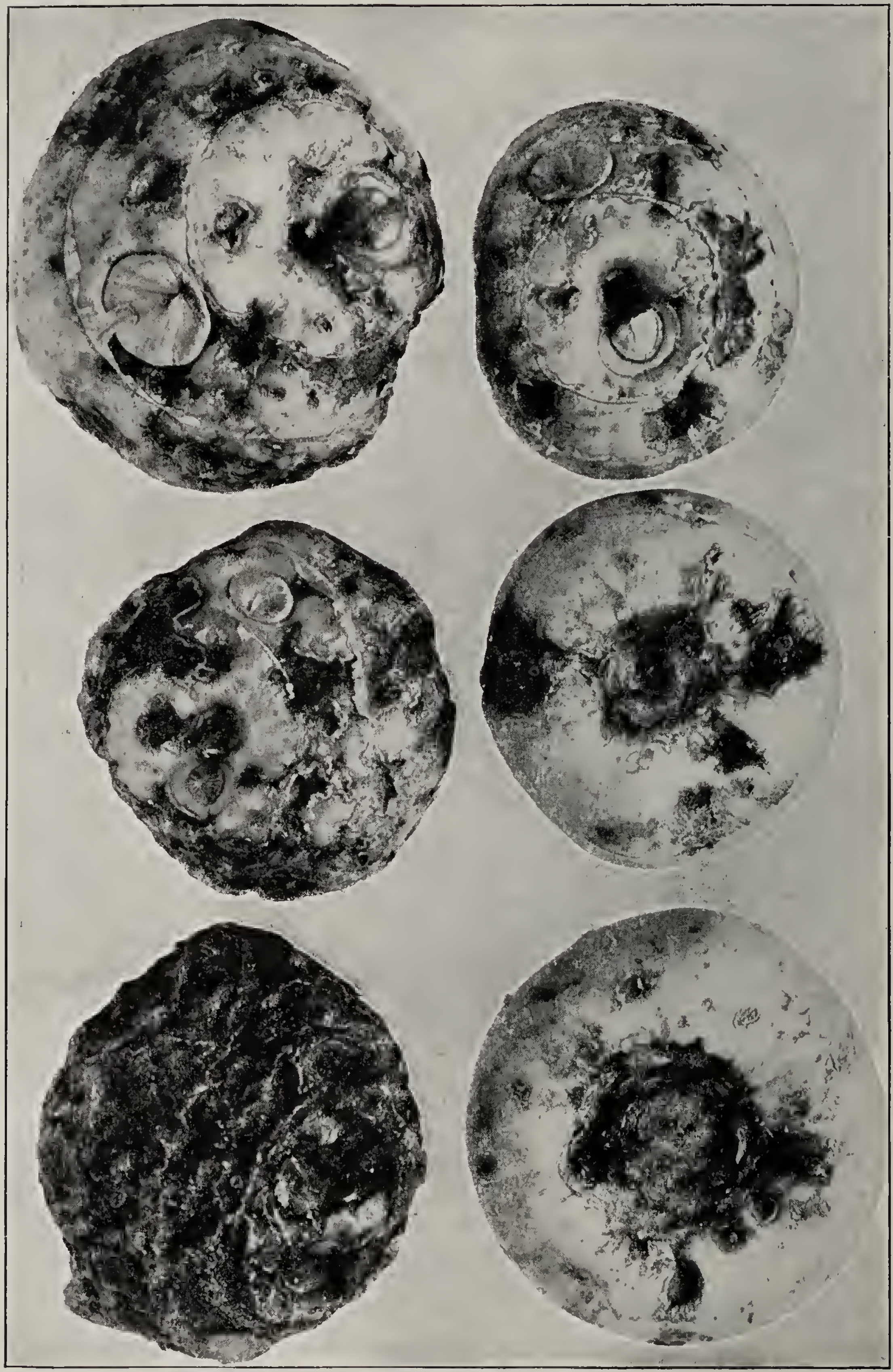
As the spot increases in size, the center becomes sunken, the color deepens to a distinct black, and the margin becomes more definite. A narrow ring, water-soaked in appearance, still indicates the advancing decay. The more definite margin of the older spots is due to the rapidity with which the sunken condition follows the advancing water-soaked area, due to drying of the tissue. The tissue gradually becomes hard, in



HARD ROT LESIONS ON LEAVES AND CORMS

1, Lesions on leaves of gladiolus seedlings. × 2

2, Lesions on corms. The two upper corms show lesions well advanced, with the diseased area blending into the healthy tissue. At the bottom the corm on the left has been cut in two in order to show the depth to which the disease has progressed. Natural size



HARD ROT LESIONS ON CORMS

Different stages in the destruction of a corm. × 1¼ some cases extremely so, making it difficult to cut the tissue with a sharp knife.

Many small lesions may coalesce into one large lesion, in some cases leaving areas of more or less normal tissue insulated in a large sunken area. Enough tissue not completely decayed may be left to indicate the margins of the formerly separate lesions. Frequently the disease advances so far that the corm is reduced to a hard, shriveled, and wrinkled mummy.

Excepting in very late stages — and in some cases not even then — the lesions do not extend deeply into the corm. The usual range is from one to five or six millimeters (Plate xv, 2). If conditions are not favorable for the development of the rot, the active border disappears, soon assuming the sunken, darkened aspect of the central part. When this stage is reached the diseased tissue can be chipped out with the finger nail, leaving the apparently healthy tissue beneath, as if the disease were not now advancing and the plant had formed a callus over the affected area.

Plants of more or less dwarfed, stunted appearance, which sometimes fail to produce blossoms, are to be found throughout the fields during the growing season. The leaves of these plants usually turn brown and die, the plant having the appearance of having died from drought. In a dry season the number of these plants is unusually large. At this time there is no decay of the new corm which is being developed, but rather the injury is caused by the premature decay of the parent corm before the offspring has developed a sufficient root system to enable it to supply its own moisture and food. This premature decay of the parent corm is not necessarily due to the advancement of the hard rot disease, but probably in most cases to the entrance of saprophytes which cause a rapid disintegration of the corm.

ETIOLOGY

The hard rot disease of the gladiolus is caused by the fungous pathogene *Septoria Gladioli* Passer. Passerini collected specimens of the leaf stage of the disease on the foliage of *Gladiolus segetum* near Parma, Italy, in June, 1874, which he contributed to Rabenhorst's *Fungi Europaei* — a collection of exsiccatæ material. On this packet of exsiccatæ material is written the original description of the fungus.[4] Passerini noted the occurrence of the disease only on the leaves. None of the other investigators found a sporulating stage of the fungus known to cause the hard rot disease of corms, and consequently the septorial fungus on the leaf was not associated with the organism causing the rot of the corms.

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[4] Rabenhorst, Fungi Europaei.
1956. Septoria Gladioli Passer. hb.
Perithecia punctiformia atra in macula exarida fulvomarginata: sporae cylindricae subrectae continuae hyalinae cirrose ejectae.
Ad folia G. segetum Vigheffio prope Parmam.
Junio 1874. leg. G. Passerini.

Life history

Pycnidia

Pycnidia (Plate xv, 1) of the hard rot fungus become visible usually within four or five days after, or in some cases even simultaneously with, the appearance of the lesion on the leaf. They are imbedded in the tissue, but protrude sufficiently to form black papillæ which are visible to the naked eye.

The pycnidia arise from intercellular mycelium (fig. 38). They measure from 100 to 160 μ in diameter by 60 to 130 μ high, the average being 127 μ in diameter by 91 μ high. The outer wall of the pycnidium consists of pseudoparenchymatous tissue which is brown in color.

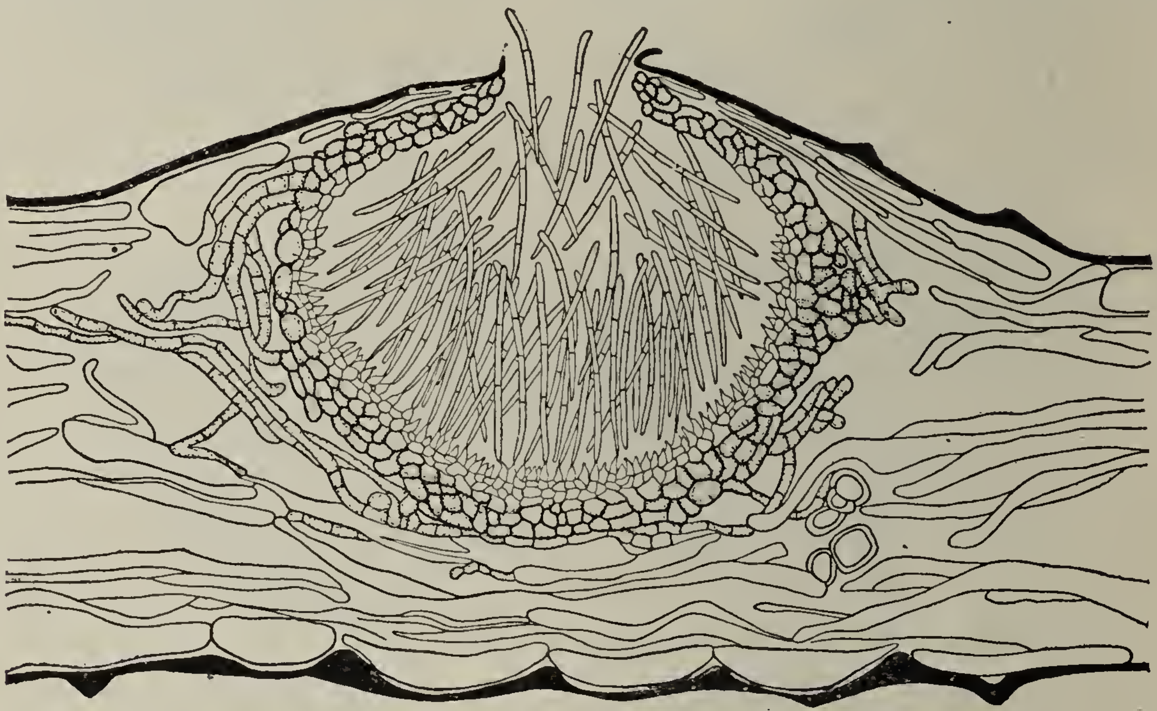

Fig. 38. PYCNIDIUM OF SEPTORIA GLADIOLI

Section through the pycnidium showing how the spores are borne. (Outlined with a camera lucida.) × 333

From a more or less inconspicuous inner layer of thinner-walled pseudoparenchymatous tissue, hyaline conidiophores arise. From these conidiophores spores are cut off by constriction. In his description of the fungus Allescher (1897) describes the spores as being unicellular and measuring from 30 to 54 μ long by 2 to 2.5 μ in diameter. However, an examination made by the writer of specimens contained in packet no. 1956 of Rabenhorst's *Fungi Europaei*, as well as of fresh material, shows that the spores are usually three-septate. As measured by the writer they are from 20 to 55 μ long by 2.25 to 4 μ in diameter, the average being about 40 by 3 μ. The spores from fresh material are cylindrical, almost straight, and hyaline.

When placed in water containing small pieces of leaf tissue, germination occurs in eighteen hours. From one to several germ tubes may develop from a single spore (fig. 39).

Mycelium

The mycelium in the corm is intercellular (figs. 40 and 41). It usually measures from 1.5 to 2.5 μ in diameter, but is in some cases even double this size. The mycelium is septate and varies from olive-brown to black in color.

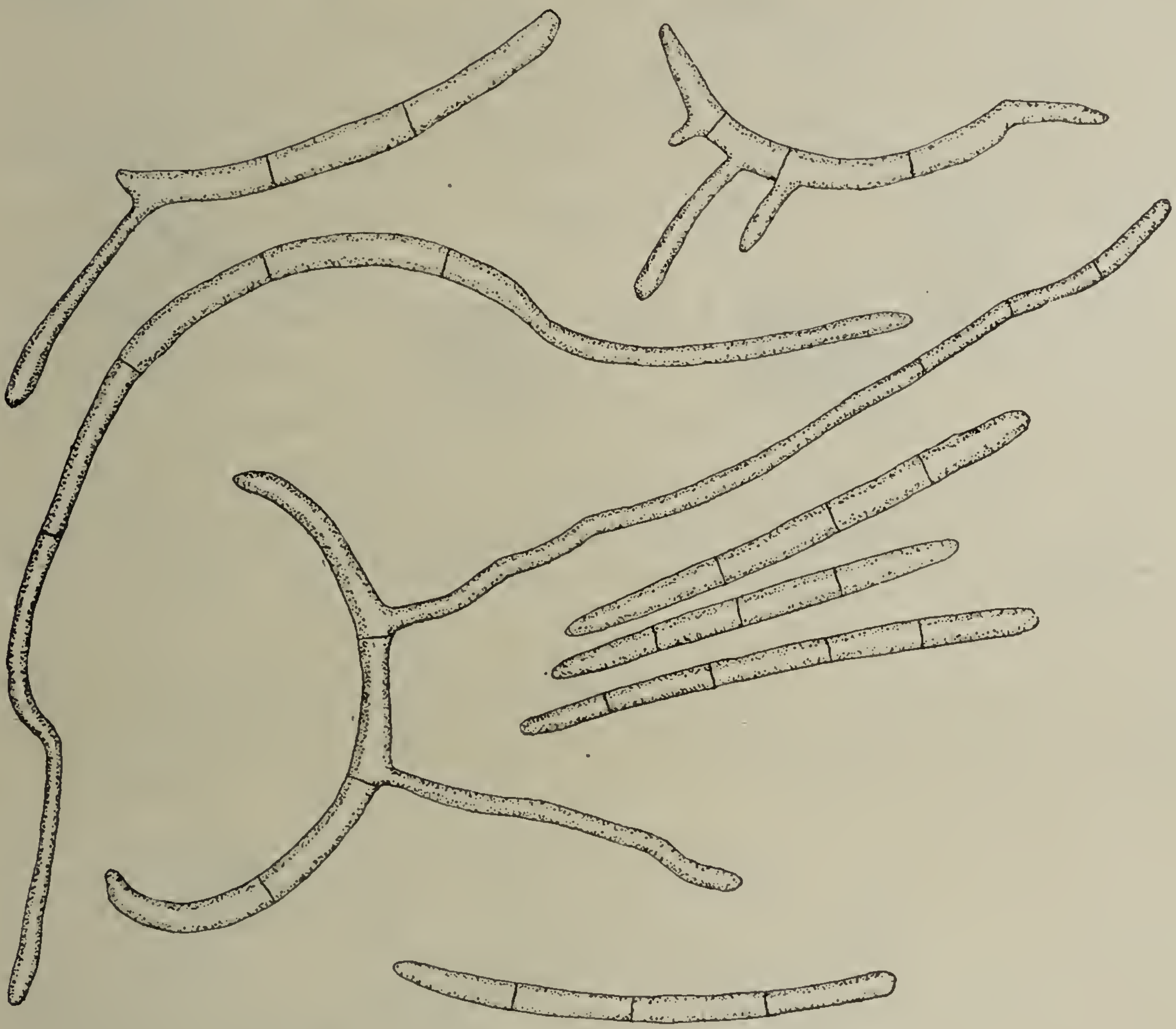

FIG. 39. SPORES OF SEPTORIA GLADIOLI
Some of the spores have germinated. (Outlined with a camera lucida.) × 666

Source of leaf infection

No sexual stage of the fungus has been found. Old leaves bearing pycnidia when exposed out of doors throughout the winter showed usually only empty pycnidia when examined the following spring. From the results of experiments subsequently discussed, apparently the mycelium of the fungus is able to live over winter in the soil. This suggests the possibility that infection is produced on the foliage by rain splashing soil containing mycelium on to the plants, or by the plants being beaten down on to the soil that harbors the pathogene. However, seedlings around which rye straw was placed to keep them off the ground and to prevent soil from being splashed on to them, were attacked by the fungus as early and as severely as those not so treated; and attempts to produce infection on the foliage of large plants by bending them over on to the soil have thus far failed. Not enough work has been done to either prove or disprove these suggested sources of infection of the foliage.

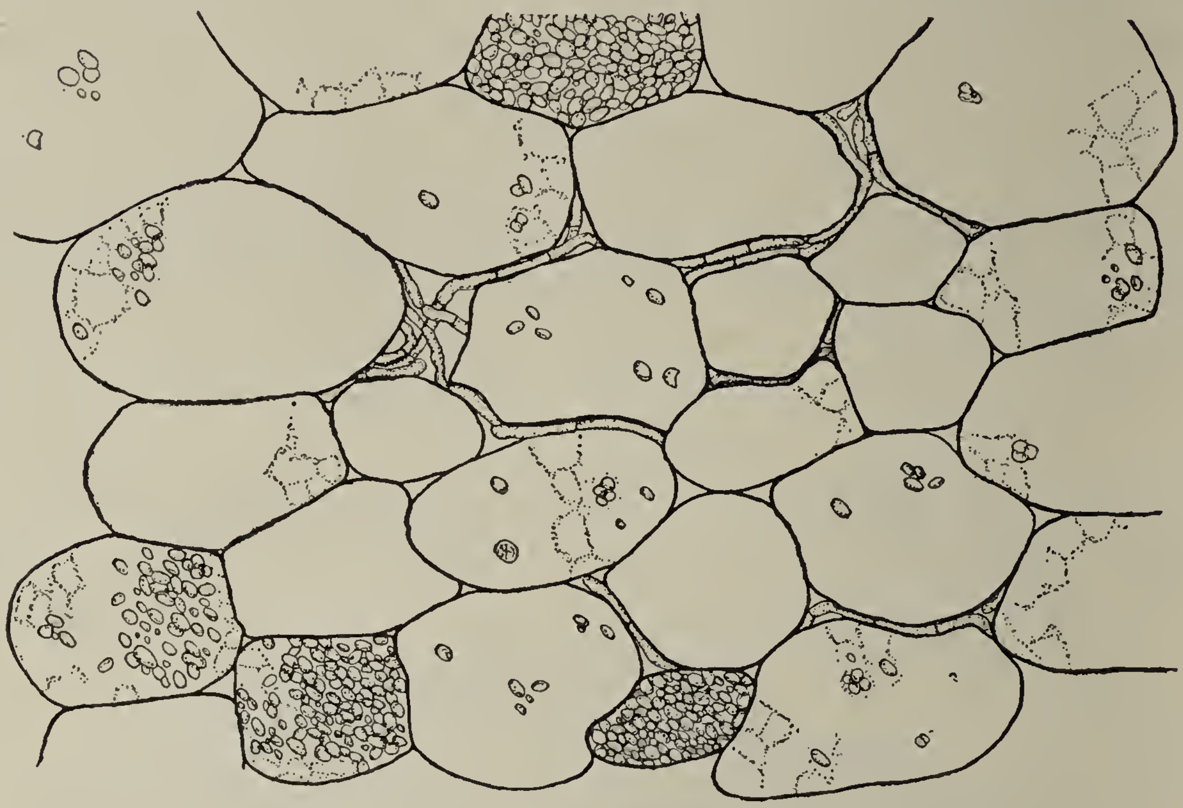

FIG. 40. HISTOLOGICAL EFFECT OF SEPTORIA GLADIOLI

Section of gladiolus corm through diseased tissue. The presence of intercellular mycelium, and the absence of starch in many cells, should be noted. (Compare with figure 41.) × 300

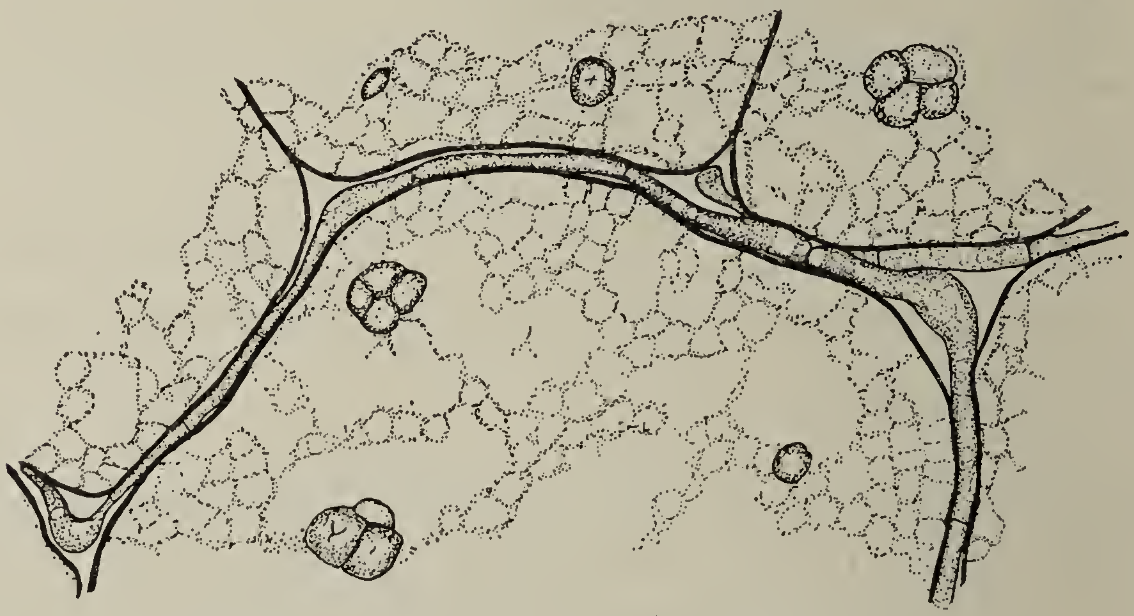

FIG. 41. MYCELIUM OF SEPTORIA GLADIOLI

The intercellular mycelium is shown much magnified. (Camera lucida drawing.) × 600

In the greenhouse, the incubation period of the fungus on plants that were sprayed with water containing spores in suspension was about twenty days.

Source of corm infection

An examination of corms harvested from seed beds where the foliage was badly diseased, has frequently shown from sixty to seventy per cent of them to be affected with hard rot. This, together with the fact that infection was produced on corms by placing in contact with them water containing spores in suspension (page 167), suggests the probability that infection is produced by spores being washed down from pycnidia formed on the foliage to the soil, where they germinate and infect the corms. As seeds are not planted very deeply, this could readily take place. It is unusual, however, for the disease to appear on the foliage of large flowering plants; and as pycnidia have not been observed to be formed on the corm, it seems that the fungus is carried over the winter primarily, if not entirely, in the mycelial stage, no spore form being necessary for the existence of the pathogene.

The fungus can be isolated from lesions on the corms at any time during winter or spring. This shows that the living organism is carried to the soil along with the corm at planting time. The offspring from diseased corms may or may not be diseased. As discussed under control (page 173), selected healthy corms grown in soil in which gladioli have never been grown have without exception given sound offspring. This indicates that the fungus is not a natural inhabitant of the soil. Furthermore, three hundred corms, all of which showed hard rot lesions, were planted in soil in which gladioli had never been grown, and seventy-eight per cent of the offspring bore hard rot lesions. Thus it seems that, in the majority of cases at least, a diseased offspring may be expected from the planting of a diseased corm.

The fungus does not grow directly from the old corm into the new one. This has been determined both by observations and by making numerous cultures from tissue at the juncture of parent and offspring. The fungus must either grow through the sheathing leaf base from the old corm to the new one, or else, as is probably the case, grow out into the soil, from which it attacks the newly developing corm.

No observations have been made which would lead the writer to believe that all infection does not occur in the field. However, it is conceivable that if corms were stored under humid conditions either in contact with one another or with moist soil, the fungus might possibly penetrate a healthy corm from an infected one or from infected soil; or, if they were stored with soil containing the pathogene around them, there is no doubt that, under moist conditions, infection could occur in the storage house as well as in the field.

Diseased corms were minced and placed in soil known to be free from the pathogene, in which two hundred healthy corms were growing. The pieces of diseased corms were merely sprinkled in among the corms before covering them with soil and no attempt was made to see that pieces were or were not in actual contact with the healthy corms. Seven per cent of the offspring were diseased.

Longevity of the organism on the foliage and in the soil

As indicated by the following experiment, the fungus is carried over winter on diseased tops:

Two hundred corms which had been grown for three consecutive years in soil that had never before been used for growing gladioli, were again planted in similar soil in 1915. Previous to planting, the corms were examined and found to be absolutely healthy. After setting the corms, tops from cormels which had been badly affected by the disease the previous year and which had remained out of doors on the ground throughout the winter, were scattered in the row. The tops and the corms were then covered with soil. These plants were harvested in September and the corms stored in a cool place. When examined early in December it was found that eighty per cent of the corms showed hard rot lesions. Practically all the diseased corms had many lesions on them, and the disease was well advanced. *Septoria Gladioli* Passer. was isolated from many of these lesions, proving that this fungus caused the disease. Healthy corms around which no diseased tops were placed but which were otherwise given the same treatment, showed no signs of disease.

The results of experiments indicate that the fungus is able not only to live over winter on old tops on the ground, but also to live in the soil throughout a period of at least four years. In 1915 selected healthy corms were planted in soil in which gladioli had been grown the previous year, and also in soil in which no gladioli had been grown for (a) one year, (b) two years, (c) three years, and (d) four years. During the intervening time the soil had been planted respectively to (a) rye and a crop of rye and vetch, (b) rye and timothy, (c) oats, hay, seeded to clover, cover crop of rye and vetch, (d) grass. In each of the five plots of ground two hundred and fifty healthy corms were planted, two hundred of them being planted in a single row and the remaining fifty in lots of ten at five different places in the field. The corms were harvested in September and stored in a cool place.

Results of these experiments were recorded the following December. Forty-seven per cent of the corms which were grown in the plot in which gladioli had been grown the previous year, were diseased, fifty per cent of the diseased corms showing characteristic hard rot lesions. The corms from the other plots were diseased as follows: (a) twenty-four per cent, forty per cent of which bore hard rot lesions; (b) twenty-three per cent, thirty-seven per cent of which bore hard rot lesions; (c) fifty-two per cent, eighteen per cent of which bore hard rot lesions; (d) forty-seven per cent, ten per cent of which bore hard rot lesions. Care was taken during the summer to avoid contaminating these plots by introducing affected soil from other fields, and the location was such that it is extremely doubtful that the wind could have entered as a factor. Since healthy corms planted in soil in which no gladioli have been grown give healthy offspring, it follows that the organism must be able to live for at least four years without the presence of the living host. No doubt decaying parts of plants were left in the soil when the last crop was harvested, but it is probable that, at least in the case of plot d, these plant parts were entirely decayed in the four years which intervened between the harvesting of the last crop of gladioli and the planting of the healthy corms used in this experiment.

Pathogenicity

The pathogenicity of *Septoria Gladioli* Passer. was established first for the mycelial stage. The mycelium of the fungus was discovered by Wallace (1909:33), who, after having observed its presence in thin sections of diseased tissue of the corm, succeeded in obtaining the organism in pure culture. He later (1910 a) succeeded in producing the characteristic lesions on experimentally inoculated corms, and reisolated the fungus. Following Wallace, Fitzpatrick (see footnote, page 154) records having produced the characteristic lesions on corms artificially inoculated in moist chambers, from which the fungus was reisolated.

Besides noting the constant association of the mycelium with lesions on corms through microscopical examinations of diseased tissue, the writer has made numerous isolations of the organism from these diseased areas. The growth of the mycelium was studied in pure culture and infection was produced at will, not only in moist chambers in sterile sand, but also in the greenhouse, and in the field under natural conditions.

Inoculation experiments

Corms were selected which after having been in the storehouse for four months showed no signs of disease. This necessitated the removal of the husks. The surface was sterilized by immersing the corm in fifty-per-cent alcohol for three minutes, then in 1–1000 corrosive sublimate solution for ten minutes, and finally rinsing in sterile water. These corms were then planted, some in sterile sand in moist chambers, some in soil in the greenhouse in which gladioli had never been grown, and some out of doors in soil never before used for the growing of gladioli.

For inoculation, mycelium growing in pure cultures on solid media was used. A bit of the medium containing mycelium was removed under sterile conditions, and in some instances smeared over a part of the uninjured surface of the corm; in other cases the corm was first injured by needle punctures and the culture was then smeared on the surface. The corms were permitted to remain in the soil for a period of two or three weeks, when they were removed and the growth they had made was cut off.

In practically all cases one hundred per cent infection was obtained. Most of the corms showed the dark brown, water-soaked areas, characteristic of the hard rot disease, when dug. The remainder showed the lesions very soon afterward. Equally as abundant infection was obtained on the uninjured corms as on those punctured by the needle. From diseased areas of the affected corms the fungus was reisolated and grown in pure culture, where its growth corresponded in every detail with the organism used for the inoculation. Corms similarly treated but having no mycelium placed in contact with them remained healthy in all instances.

In order to further test the ability of the fungus to produce disease, sound corms were planted in soil in which gladioli had never been grown, and permitted to grow to maturity. On August 15, 1914, as the offspring were developing from the parent corms, the soil was inoculated with mycelium of the fungus. The inoculum was prepared by grinding cultures of the organism on oatmeal agar with cornmeal, and was applied by placing a small handful of the mixture around each corm in immediate contact with it. Of the one hundred corms thus inoculated, seventy-three showed characteristic hard rot lesions when the results of the experiment were recorded the following December. Reisolations of the fungus were obtained from many of the diseased corms. Corms from plants which had not been inoculated with mycelium remained absolutely healthy.

The above experiments prove the ability of the mycelial stage of the hard rot fungus to attack gladiolus corms. The experiments given below show that this mycelium is but a stage of *Septoria Gladioli*, which Passerini described as occurring on the foliage of *Gladiolus segetum* in Italy.

A pure culture of the fungus *Septoria Gladioli* Passer. was obtained from the germination of a single spore from a pycnidium formed on the leaf of a gladiolus seedling. The resulting fungous growth was identical with that obtained from isolations from small pieces of diseased corm tissue. Mycelium thus obtained from a single spore was used to inoculate healthy corms, some of which were planted in moist chambers in sterile sand, others in soil in the greenhouse known to be free from the pathogene, and still others out of doors in soil in which gladioli had never been grown. Numerous experiments were performed, and in all cases one hundred per cent infection was obtained by smearing a small quantity of an agar culture of the mycelium from a single spore on the surface of the corms. The fungus was reisolated from diseased areas on the corms, and its growth in pure culture was found to be identical with the organism previously isolated from corms and from the germination of a single pycnospore.

In order to test the ability of the fungus isolated from a lesion on a corm to attack the foliage, a small piece of an agar culture of the organism was mixed with a little sterile distilled water and painted on the foliage of seedlings and flowering plants growing in the greenhouse. The seedlings were then inclosed in bell glasses lined with moistened filter paper, while the parts of the large plants on which the mycelium was placed were inclosed in a lamp chimney stoppered at both ends with cotton. Seedlings and large plants were similarly treated with mycelium obtained from the germination of a single pycnospore. Plants were similarly treated, except for the omission of the mycelium, to serve as a check.

Inoculations were successful with both the mycelium from the germinated spore and that from the diseased corm. Infection was evident on the seedlings within ten days. The lesions differed somewhat from those found under natural conditions, infection manifesting itself in the form of large, dark, water-soaked areas, with the early death of the entire area over which the inoculum was painted. The lesions produced by mycelium from the two different sources were similar.

On the large plants, infection was observed within fourteen days after inoculation, the lesions being identical on the plants inoculated with mycelium from the two different sources. At first a dark area, water-soaked in appearance, was formed, and then the lesions turned brown due to the death of the tissue. The lesions in no case extended much farther in area than that covered by the culture of mycelium painted on the foliage. The most significant fact is that pycnidia developed in these lesions on the leaf on practically all of the twenty-four plants inoculated with the mycelium, regardless of whether the mycelium was from a germinated spore or from a diseased corm. Although many pycnidia failed to reach maturity, spores were formed in several of them. These spores were germinated and the fungus was obtained in pure culture.

In October, 1914, Septoria-like spores were found in a culture of the organism isolated from a diseased corm. These spores, together with others obtained from pycnidia on seedling leaves, were used in the following experiments:

Seeds were planted in three flats in the greenhouse and the plants were permitted to grow until they were from two to four inches high. The plants in one flat were sprayed with water containing, in suspension, spores from a culture of the fungus isolated from a diseased corm; the plants in the second flat were sprayed with a suspension of spores from pycnidia formed naturally on seedlings; the plants in the remaining flat were sprayed with water containing no spores, for a check. The seedlings were then covered with bell glasses lined with moistened filter paper, and the three flats were placed in a large moist propagating chamber for seventy-two hours.

An examination of these seedlings twenty days after they had been sprayed with the suspension of spores in water showed evidence of infection. Small yellowish brown areas were apparent and numerous pycnidia appeared in these lesions a few days later. The lesions were characteristic of those found on the seedlings under natural conditions. The check plants alone remained healthy, infection occurring on plants which were inoculated either with spores from culture or with spores from pycnidia formed under natural conditions. The fungus was again obtained in pure culture from the germination of single spores from pycnidia formed on both lots of infected plants.

It then seemed desirable to determine whether or not corms could become infected by spraying spores upon them. The surfaces of thirty healthy corms were sterilized by immersing them first in fifty-per-cent alcohol for three minutes, then in 1–1000 corrosive sublimate solution for ten minutes, and finally rinsing in sterile water. Ten of these corms were then planted in each of three moist chambers containing moist sand which had previously been subjected to steam at ten pounds pressure for two hours. Corms that were particularly depressed at the crown were selected for the experiment, in order that a cubic centimeter or more of water could be held in each of these cavities. Water containing spores in suspension was placed in the depressed areas of the corms in two of the moist chambers. The spores for one chamber were obtained from pycnidia formed naturally on the foliage of seedlings, while for the other chamber the spores were obtained from a culture of the fungus isolated from a diseased corm. The third chamber was used for a check, water containing no spores being placed in the cavities of the corms. One-half of the corms in each chamber were then pricked with a sterile needle in the area covered by the water.

Observations made twenty days later showed most of the corms in the two chambers which were inoculated with spores to be infected. Six days later, when they were removed, all the inoculated corms showed the characteristic hard rot lesions, while the check corms remained healthy. Lesions were as abundant on corms that had not been injured as on those punctured with the needle. About one-half of the corms showed hard rot lesions on the sides, where evidently spores had been washed over from the concave crowns. The fungus was isolated from many of these diseased areas and again obtained in pure culture.

In the spring of 1915 healthy corms were planted in soil in which gladioli had never been grown, and allowed to grow to maturity. On August 21 the soil was removed from around thirty of these plants and water containing a suspension of spores was poured around the corms. At this time the offspring were about one-half inch in diameter. The spores for inoculating fifteen of the corms were obtained from pycnidia formed naturally on the foliage of seedlings, while for the other fifteen corms the spores were obtained from a culture of the fungus isolated from a diseased corm. For a check, corms were given the same treatment except that the water poured around them contained no spores. The soil in which these plants were growing was kept moist for the following three days.

The corms were harvested in the following September and stored in a cool place. When examined in November it was found that ten of the fifteen corms inoculated with spores from pycnidia showed hard rot lesions; also, six of the fifteen corms inoculated with spores from culture showed lesions characteristic of the hard rot disease. The check plants remained healthy. This experiment is significant in showing not only that spores from cultures and from naturally formed pycnidia are able to infect the corms, but also that it is possible for infection to occur on the corms from spores discharged from pycnidia on the leaves. The spores are washed down into the soil, where they germinate and produce infection.

Pathological histology

Leaf

An examination of thin sections of leaves bearing young diseased areas shows the lesion produced by the fungus to be necrotic. The cells turn brown, shrivel, and collapse (fig. 42). Here and there a cell may be found filled with a yellow, granular or oil-like substance the identity of which is undetermined. The diseased area is usually but from one-third to one-half the thickness of the healthy tissue.

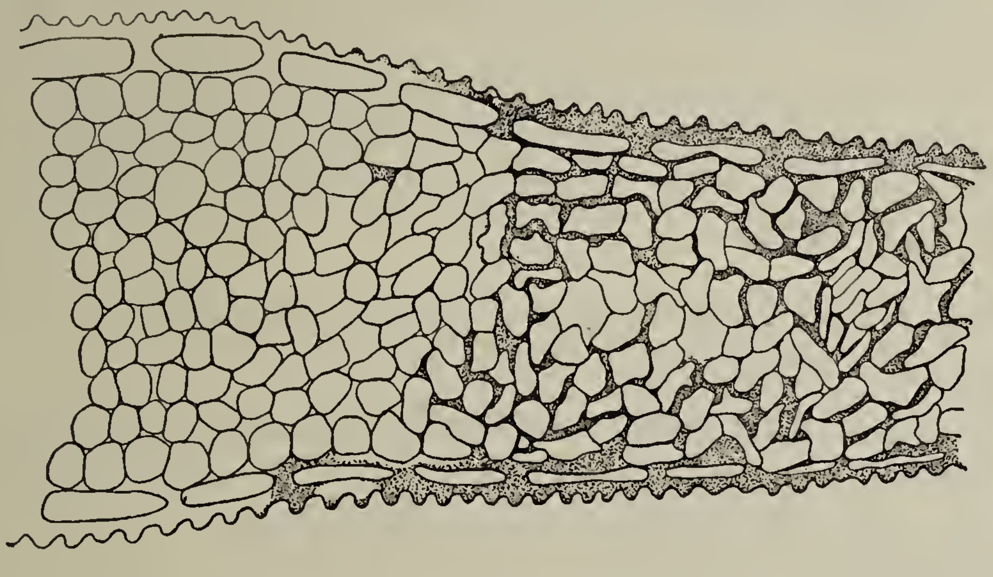

FIG. 42. HISTOLOGICAL EFFECT OF SEPTORIA GLADIOLI

Camera lucida drawing of a free-hand section through a hard rot lesion on the leaf of a seedling. The cells are beginning to shrivel and collapse. × 200

Corm

In order to study the histological changes that occur in the corm, comparative studies of healthy and diseased tissues have been made. Both microtome and free-hand sections have been used, the former being less satisfactory because of the difficulty encountered in sectioning prepared material. Sections were stained with a weak solution of iodine in order to study starch content of cells, and with Haidenheim's iron-alum-hæmatoxylin and aniline blue for a general study of the tissue.

While the cells of healthy tissue are densely packed with starch, those of diseased tissue show but very few starch grains or none at all (figs. 40 and 41 [page 160], and 43). This, together with the deposit in the diseased area of a yellow substance of undetermined composition, is the most pronounced effect to be noticed by comparing sections of diseased and healthy tissue. Especially in the early stages of the disease, nuclei and even the cytoplasm appear but slightly disturbed. The cell walls retain their shape for some time after the starch has disappeared. Later, shrinkage takes place and the cells collapse, the walls becoming distorted and broken. This last effect is no doubt due to loss of moisture rather than to any direct action of the fungus.

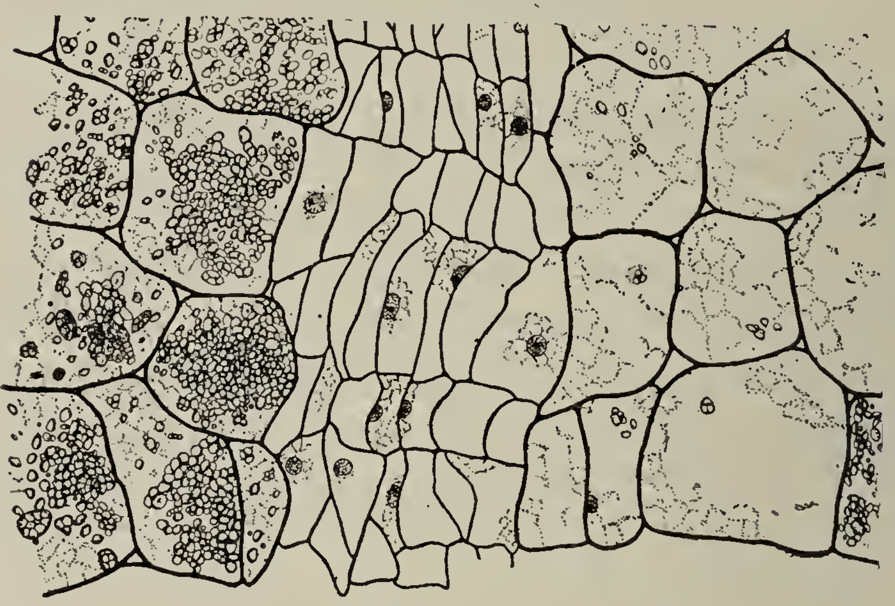

FIG. 43. HISTOLOGICAL EFFECT OF SEPTORIA GLADIOLI

Camera lucida drawing of a microtome section through medium of healthy and diseased tissue. The layer of comparatively thin-walled cork cambial cells separating the starch-filled healthy cells from the diseased cells, which contain little or no starch, should be noted. × 300

A layer of cork cambium is formed at the juncture of the diseased and the healthy tissue (fig. 43). Young, actively advancing lesions do not show this layer of thin-walled cells, but it is to be found in those instances in which it appears that the advance of the disease has been checked and the canker healed. In cases in which the diseased area can be chipped out, the break is at this layer of cork cells.

Cultural characters of the fungus

Pure cultures of *Septoria Gladioli* Passer. were obtained from isolation plantings of diseased tissue from a corm. The surfaces of corms showing hard rot lesions were disinfected by immersing them in fifty-per-cent alcohol for three minutes, then in 1–1000 corrosive sublimate solution for ten minutes, and finally rinsing in sterile water. By means of a sterile scalpel the surface of the corm was cut away and a small piece of the tissue at the advancing margin of the lesion was removed to a sterile medium. Comparatively few contaminations were obtained in the large number of isolations made in this manner.

No marked difference was observed in the growth of the mycelium on nutrient or on soil-extract agar, or on other solid media consisting of agar and various plant decoctions, such as of gladiolus, potato, oats, corn, and beans. On the other hand, rolled-oat agar[5] proved slightly more favorable for mycelial growth, and spores were produced by the fungus only when growing on this medium. For this reason rolled-oat agar was used almost entirely for culturing the organism during the last year of study, and the following cultural characters of the fungus are a record of its growth on this medium.

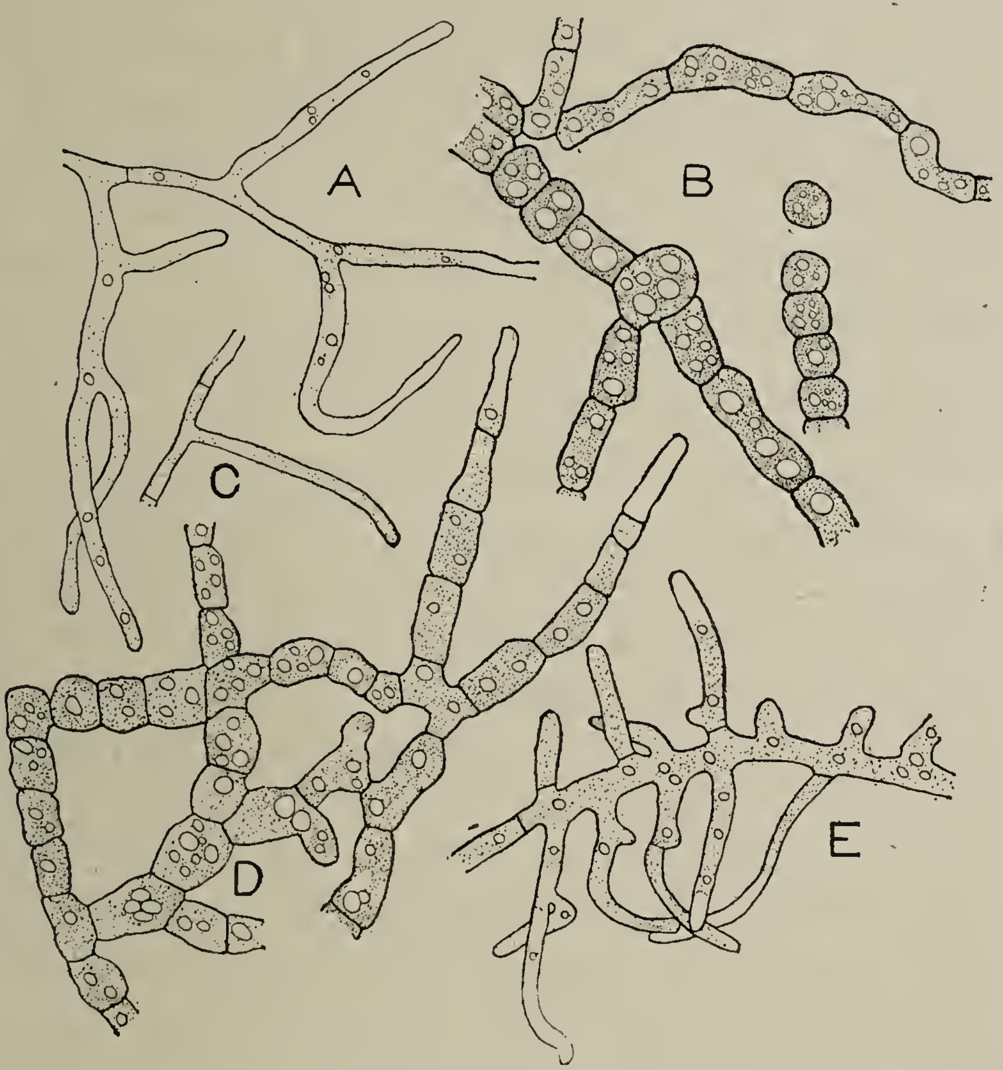

FIG. 44. MYCELIUM OF SEPTORIA GLADIOLI

Camera lucida drawing of mycelium of the hard rot fungus growing on rolled-oat agar. A, colorless strands of hyphæ radiating from a bit of diseased tissue. B and D, cell walls that have thickened, the cells having assumed a globose form. C, colorless hyphæ to be found in old cultures. E, an intermediate stage between A and B. × 600

Macroscopically, no growth from bits of diseased tissue placed in medium in previously poured petri dishes is evident for from seven to fourteen days. However, if the plate is examined under the low power of the microscope, mycelium radiating from the transferred piece of tissue can be seen in about four or five days from the time of making the culture. Frequently the first macroscopical evidence of growth is the appearance of a black growth on the transferred piece of tissue, which may be completely covered before the organism invades the medium. Soon a dense, black colony spreads very slowly into the surrounding medium. After growth of a month the colonies usually do not exceed one or two centimeters in diameter. If portions of a colony are transferred to flasks of media or to other plates, the resulting growth is somewhat more rapid.

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[5] The rolled-oat agar was prepared as follows: 50 grams of rolled oats, in 700 cubic centimeters of distilled water, was cooked in a double boiler for about an hour, or until the oats were thoroughly cooked through. Most of the solid matter was then squeezed through cheesecloth. To this was added 15 grams of agar and enough water to make one liter of medium.

Some of the characters of the mycelium as grown in culture are shown in figure 44. The first strands of hyphæ to be seen radiating from the piece of diseased tissue are hyaline (fig. 44, A). Color frequently makes its appearance in streaks, which radiate from the piece of diseased corm, where the hyphæ seem to become gnarled. Cells of the much-septate mycelium thicken, assuming a globose form (fig. 44, B). Well-defined globular bodies, which appear to be oil drops, soon appear within the cells. Osmic acid causes these to turn brown. The walls turn brown with the appearance of these bodies, giving the colony its black color when viewed macroscopically. The globose or subglobose cells of the hyphæ may remain attached, forming chains, or may separate into individual cells (fig. 44, B).

Although the growth is usually confined beneath the surface of the medium, small scant patches of white, aërial mycelium are found occasionally. The hyphæ of old cultures is of two kinds: one of comparatively long, colorless cells measuring from 1.5 to about 4 μ in diameter (fig. 44, C, E); and one of short, thick, globose cells containing the oil drops mentioned above, measuring from 3 to 6 or 7 μ, or sometimes even 12 μ, in diameter (fig. 44, B, D).

Scattered through the colonies are areas which under the microscope appear denser and blacker than other areas. These seem to be caused by a gnarling, or balling, of the hyphæ at these points, together with the anastomosing of cells of different hyphæ, as if pycnidia or other fruit bodies were to be formed. Cultures have been examined intermittently throughout a period of over three years, and no further development of these masses of hyphæ has been observed.

Spores of *Septoria Gladioli* Passer. were first observed in culture in October, 1914. The mycelium on which these spores were formed was isolated in the preceding June, from a hard rot lesion on a corm. This mycelium was allowed to grow in a tube of rolled-oat agar from June until August 20, when a square block of the medium containing mycelium was transferred to the slanted surface of about 200 centimeters of rolled-oat agar contained in a 300-cubic-centimeter Erlenmeyer flask. The medium contained in this flask was freshly prepared. There were about 10 cubic centimeters of water of condensation in the flask at the base of the slanted medium. The culture from which the transfer was made was well dried at the time when the square of medium containing mycelium was removed, and this condition may have influenced spore formation when the mycelium was placed on the freshly prepared medium.

By approximating the above conditions the writer has been able to bring about the formation of spores in cultures of the mycelium from other sources than the one above noted. Spores were formed in a culture of the mycelium obtained from the germination of a single pycnospore formed naturally on the leaf. Spores formed in cultures of mycelium isolated from corms and from germinated pycnospores were identical in shape and size, thus materially helping to establish the identity of the two previously unconnected organisms.

Spores in culture have always appeared as minute pinkish white pustules on the upper edge of the block of medium containing mycelium transferred from the old culture. Later these pustules may appear scattered over the surface of the medium of the flask to which the transfer was made. If at this time transfers are made from this flask to another, the pustules are formed more readily and in greater abundance.

Owing to difficulties encountered in obtaining sections or mounts of these pinkish white elevations, but little is known of their structure, especially in reference to the formation of the spores. Normal pycnidia such as those formed on the foliage are not produced. The spores are formed in a very loose stromatic mass. There is an abundance of dense, pinkish white mycelium, which is still in evidence after spores are no longer to be found associated with the pustules.

Spores formed in culture are variable in size, ranging from 25 to 97 μ by 1.8 to 3.75 μ, the average being 58 by 2.71 μ. Dilution plates of these spores were made in nutrient agar and practically one hundred per cent germination was obtained within a period of eighteen hours. The resulting mycelial growth was not so brown in color as that isolated from corms. Many minute, black dots appeared, which, when examined under the microscope, proved to be aggregations of short, thick-walled cells formed commonly and more abundantly in cultures of the fungus isolated from corms. Transfers were made from these plates to tubes of rolled-oat agar, where the resulting growth was identical with that obtained by isolations made from diseased corms.

In order to correlate the growth of mycelium isolated from diseased tissue of corms with that isolated from the leaf, dilution plates of spores from naturally formed pycnidia were made. From these dilution plates individual spores, which were so located that they could be removed singly, were transferred to other plates where germination was observed under the microscope. The resulting mycelial growth in all cases has been identical with that isolated from corms when the two were growing under similar conditions.

CONTROL

The great need of some method of combating the organisms causing rots of gladiolus corms was early impressed upon the writer, and many suggested methods of general application were tried for the control of the rots collectively rather than separately. Another disease, designated by Wallace (1909:61) as dry rot, was found to be present along with the hard rot disease in stock which was used in all control experiments. The lesions produced by the fungi causing these two diseases are so similar that they can be distinguished only in the earliest stages, and not even then with a great degree of accuracy. Cultural isolations of the organisms will often show a lesion to have been caused by the hard rot fungus when it was selected as being a dry rot lesion, or vice versa. Not only are the lesions produced by the two fungi similar, but the life histories of the organisms are not materially unlike except for the fact that no spore form of the dry rot fungus has been found. From all indications, a treatment applicable to the control of one disease should be of value in controlling the other. At least fifty per cent of the corms used for experimental purposes were affected with the hard rot disease. This estimate is based on observations and cultural studies throughout a period of several years. In practically all cases, after the corms were treated, the organisms have been isolated from diseased areas in order to make it absolutely certain that both were present, and in no case has any treatment resulted, so far as the writer was able to judge, in materially changing the ratio of the corms affected by the two diseases.

In view of the fact that control experiments were conducted previous to, and simultaneously with, life history studies, it is not surprising that some treatments which at first seemed worthy of trial failed to bring results. Many of the following treatments have given negative results. This does not wholly deprive them of their value, for they serve to narrow down the field of experimental possibilities of control. Many data have been obtained from the treatments which will be valuable in a further study of control measures.

SEEDLING TREATMENTS

The hard rot disease on the foliage of seedlings has been materially reduced by spraying with bordeaux mixture used at the strength of five pounds of copper sulfate and five pounds of lime to fifty gallons of water. In 1914 the first spray was applied on July 17. This application was followed by eight other treatments made at intervals of about seven days. Because of the smooth surface of the foliage, it was necessary to use a "sticker," or adhesive, to cause the fungicide to adhere to the plants. The " sticker " used consisted of resin two pounds, sal soda (crystals) one pound, and water one gallon, which, after being boiled until a clear brown color was obtained, was added to each fifty gallons of the bordeaux solution. The seedling beds were sprayed twice the same day for each application, the second spray being applied as soon as the first was dried on the foliage. This was done in order to thoroughly cover the plants. A hand sprayer was used, in which a pressure of from three and one-half to five pounds could be maintained at all times.

H. H. Groff, of Simcoe, Ontario, informed the writer that he was successful in controlling a disease of the foliage of seedlings by spraying with a solution of copper sulfate in water. Specimens of the disease sent by Mr. Groff to the writer proved to be the hard rot disease. From the nature of the foliage of the gladiolus, it is probable that the plant is more resistant to spray injury than are most plants and that a solution of copper sulfate could be used without causing injury. However, no experiments have been conducted by the writer using copper sulfate solution as a spray for the control of this disease, and it is very unlikely that results could be obtained, because the copper sulfate would be washed away with the first rain.

Although spraying will greatly reduce the amount of disease on the foliage, a simpler and more efficient method is to plant the seed in soil in which gladioli have never been grown. When this was done, and care was taken not to carry parts of diseased plants or soil bearing the fungus to these seedlings, it was found that not a single diseased plant appeared during the summer. The corms of these plants were materially larger when harvested than the corms of plants whose foliage was attacked by the hard rot fungus, and no evidences of disease on the corms were observed. This is the logical way to control the hard rot disease, which causes so much damage in seedling beds. It is doubtful whether any grower plants such a large quantity of seed, or has such a limited area of ground, that soil in which gladioli have never been grown cannot be obtained for this purpose. If this plot is kept isolated and care is taken not to introduce the pathogene into the soil, there appears to be no reason why seedlings cannot be grown on the same area year after year, if necessary, at least so far as the hard rot disease is concerned.

CORM TREATMENTS

Healthy corms in soil free from the pathogenes

Selected healthy corms have been grown for the past four years in soil in which no gladioli had ever before been planted, without a single corm's becoming diseased. The fact that these corms were stored throughout each winter in a room containing diseased corms leads to the conclusion that the fungi causing the hard rot and dry rot diseases are not disseminated in storage. It is obvious that in order to obtain results from the selection of healthy corms, rigid and painstaking care must be exercised to select corms known to be absolutely free from disease. Any doubtfully healthy corms must be rejected, for a single diseased corm may serve to infect the soil in which healthy corms are planted.

To select healthy corms it is necessary to remove the husks and to be sure there is no evidence of disease on the corms. It is best to do the selecting in the spring, as near planting time as possible, for, whereas a corm may be infected in the fall at digging time and still show no evidence of being diseased, the lesion is sure to be noticeable by planting time. Previously to planting these corms it is advisable to treat them with a five-per-cent solution of formalin for thirty minutes, in order to kill any parts of the pathogenes which may be clinging to them.

In 1912 from two thousand to three thousand healthy corms were selected in the manner suggested above. They were planted each year in soil that had not been under cultivation for about twenty years. A commercial phosphate fertilizer was applied to the experimental plots at the rate of about five hundred pounds to the acre, and the corms were planted in the usual manner. Care was exercised to see that no foreign soil nor diseased plant parts were introduced into these plots. The plants received the usual amount of cultivation and were subjected to the same conditions as commercially grown plants. Spikes of flowers were cut during the blooming season, and the corms were harvested and stored each autumn in the ordinary way.

This process of selecting healthy corms and growing them in soil free of the pathogenes is the only means known that will give an absolutely healthy crop. Of course the large amount of labor, the carelessness of laborers, the need of a larger outlay of land, and the inability to procure land on which gladioli have never been grown or at least not for many years, are some of the important factors that will at once suggest themselves to growers, especially the larger growers who produce many thousands of corms annually. It is admitted that this is a slow and somewhat undesirable method from many standpoints, yet it is a process that has proved conducive to results, and undoubtedly can find some application by all growers. Small growers can readily and with no great loss adopt such a method for growing gladioli. Larger growers can adopt the process in part.

Such a method could be begun on a small scale, by selecting as many healthy corms the first year as conveniently possible and planting them in soil in which gladioli had never been grown. More selected corms could be added to this lot the second year, and so on until the grower gradually worked away from diseased to healthy stock. The opportunity for healthy corms to become diseased is thus lessened, and diseased conditions are in general improved.

Healthy corms in soil known to harbor the pathogenes

When selected healthy corms were planted in soil in which gladioli had been grown the previous year, the offspring were diseased. The amount of disease varied from twenty-three to forty-seven per cent. The possibility suggested itself that some treatment might be devised which would protect the offspring of the sound corms that were planted, from the pathogenes that must be in the soil.

An experiment was conducted in 1914 in which the corms of the various plots were treated with different chemicals. A small handful of the chemicals was placed over each corm previously to covering the corms with soil. The chemicals used were: plot 1, sulfur; plot 2, air-slaked lime; plot 3, acid phosphate; plot 4, soot. The soot was suggested by a grower who claimed to have obtained good results through a liberal application of this substance to the soil. The plants received ordinary cultivation during the summer, and the offspring were harvested and stored in the usual manner. In December, when the results of the experiments were recorded, it was found that none of the treatments were of any value, the percentages of disease in the treated plots being practically the same as that in a check plot where no treatment was given. The experiment was repeated in 1915 with the same results.

Diseased corms in soil free from the pathogenes

Spring treatments

When diseased corms that had received no treatment were planted in soil free from the pathogenes, it was found that the offspring gave various percentages of disease. Seventy-eight per cent of the offspring from three hundred corms bearing typical hard rot lesions, which were planted in soil free from the pathogenes, were diseased. In other instances, thirty-three and fifty-seven per cent diseased offspring, respectively, were recorded from the planting of two lots of three hundred corms affected with either hard rot or dry rot, or both.

An experiment was conducted in 1914 to determine whether or not some treatment could be given these corms at planting time which would lessen the amount of disease in the offspring when the corms were grown in soil free from the pathogenes. Corms that bore typical hard rot lesions, and others that were affected with either the hard or the dry rot disease or both, received the following treatments: (1) formalin at the rate of one pint of commercial formalin to fifteen gallons of water, for eighteen hours; (2) corrosive sublimate, 1–1000 solution, for eighteen hours; (3) chemicals, in which the corms were rolled and with which they were covered after being placed in the rows and before covering them with soil. The chemicals used were sulfur, air-slaked lime, acid phosphate, and soot. The corms were planted in soil in which gladioli had never before been grown, and received ordinary cultivation during the summer.

When the corms were examined in December, 1914, the results obtained indicated that none of the treatments were effective in reducing the amount of disease. The experiment was repeated in 1915, with the same results except that corms over which a handful of sulfur was placed were injured severely by the chemical. Such treatments of diseased corms have proved to be of no value in controlling the hard rot and dry rot diseases.

Autumn treatments

Since the lesions on corms attacked by the hard rot and dry rot organisms are materially smaller in the autumn when the corms are dug than in the winter, it was thought that possibly the corms could be given some treatment at digging time whereby the pathogenes within the tissues would be killed. Consequently the following experiments were performed with the hope of at least lessening the extent of injury to the corms.

Experiment 1. Treatment of corms with formalin and corrosive sublimate solutions.— In 1914 one thousand corms, of which many had lesions in various stages of advancement at digging time, were treated, immediately after digging, with formalin at the strength of one pint of commercial formalin to fifteen gallons of water, in which they were left for eighteen hours. An equal number of corms were treated with 1–1000 corrosive sublimate solution for eighteen hours, and an equal number were left untreated for a check. After treatment the corms were cured out of doors and then stored as usual.

In the following December, when the results of these treatments were recorded, it was found that neither had reduced the amount or the extent of the diseases. Thirty-five per cent of the offspring from the untreated corms were diseased, while thirty-seven and thirty-eight per cent, respectively, of the offspring from the corms treated with formalin and corrosive sublimate solution were diseased.

The same experiment had been performed the previous season (1913), with the result that about ninety per cent of the corms of both the treated lots were diseased while the corms in the check were but seventy per cent diseased. This remarkable situation is difficult to explain. There was a prolonged period of wet weather about the time the treatments were made, so that the corms remained wet for about a week after they were treated. The corms were either injured by being subjected to the action of the reagents for so long a time, or else the increased percentage of diseased corms was due to some other abnormal condition brought about by the wet condition of the corms. Many of the corms bore lesions which were not characteristic of either the hard rot or the dry rot disease, from which neither the dry rot organism nor *Septoria Gladioli* Passer. could be isolated.

Experiment 2. Formaldehyde gas as a disinfectant.— On the basis of successful experiments performed for the control of potato scab by the use of formaldehyde gas, diseased corms were subjected in 1913 to a similar treatment. Obviously this would eliminate the humid condition arising from the use of solutions.

In this experiment the gas was generated by the potassium permanganate method. At harvesting time one thousand corms were placed, immediately after digging, in shallow trays in a large air-tight box. The formaldehyde gas was obtained by using enough potassium permanganate to generate gas at the rate of three pints of formalin and twenty-three ounces of permanganate crystals to five hundred cubic feet of space, it having been previously determined that corms thus treated were unharmed. The treatment extended over a period of twenty-four hours. The corms were then thoroughly cured in the open air and stored as usual.

In January, 1914, when the results of this treatment were recorded, it was found that sixty-nine per cent of the corms were diseased while seventy per cent of the untreated corms from the same lot were diseased. The hard rot and dry rot organisms were isolated from many lesions, showing both organisms to be alive. The difference of one per cent in the amount of disease can easily be explained on the basis of experimental error, with the resulting conclusion that formaldehyde gas as used in this experiment is of no value in controlling the corm rots of gladioli.

Experiment 3. Hot-water and hot-air treatments of diseased corms.— In a third experiment some means was sought whereby diseased corms could be subjected to heat, which would kill the organisms within the tissue without causing injury to the corms. After such treatment the corms could be planted in soil known to be free of the pathogenes and be depended on to yield a healthy crop.

Previously to conducting the experiments it was determined that the thermal death point of the hard rot and dry rot organisms was about 50° C. when subjected to this temperature in a test tube culture for a period of ten minutes. The tubes were immersed in the hot water as soon as new growth appeared from pieces of medium containing mycelium which were transferred to the tubes. It was also previously determined that corms of from three-fourths inch to one and one-half inches in diameter, when subjected to dry heat at 50° C. for one and one-half hours or to water at this temperature for one-half hour, were not materially harmed.

Having thus obtained some idea of the relative resistance of both corms and the two pathogenes to heat, corms were subjected in 1913 to dry heat and to water at 50° C. for one and one-half hours and one-half hour, respectively, and the progress of the disease was noted. There was enough difference between the length of time required to kill the fungi and that which caused no injury to the corms to warrant this treatment. The corms used were of a single variety and showed considerable disease when dug. They were treated on the same day that they were harvested. For the hot-water treatment a half-bushel galvanized iron measure was used, the heat being supplied by an oil-stove flame, and for the dry-air heating a Freas electric oven was used. After treatment the corms were cured as quickly as possible and then stored in a cool place as usual. Wet weather lengthened the time necessary to thoroughly cure the corms more than was desirable.

In the following January, when the results of this experiment were recorded, it was found that seventy per cent of the untreated corms bore lesions of either the hard rot or the dry rot disease, while of those treated with dry heat and hot water eighty-five and ninety-five per cent, respectively, were diseased. In both cases in which treatments were given, the corms, besides containing a large percentage of disease, showed the lesions to be more advanced than those in the check. Both the hard rot and dry rot organisms were isolated from many diseased corms of both lots, showing the pathogenes to be still alive.

In accounting for the increased percentages of disease in the treated over the untreated corms, it was found that many of the lesions, besides being different in appearance from those produced by the two fungi, were identical with those produced on healthy corms which were subjected to heat under the same conditions and from which neither the hard rot nor the dry rot organism could be isolated. These lesions were undoubtedly due to injury caused by the heat. However, a sufficiently large number of corms bore characteristic lesions of the two diseases, and the causal organisms were isolated from enough lesions, to prove that the treatments were a failure in killing the fungi within the tissue at a temperature that would not injure the corm.

SOIL TREATMENTS

Experiment 1. Chemicals.— Since the organisms causing the hard rot and dry rot diseases are able to live over winter in the soil, the possibility suggested itself that some chemical might be applied to the soil which, either through its toxicity or by its ability to change the composition of the soil thereby rendering it unsuited for the existence of the pathogenes, would serve to eradicate them. Healthy corms could then be planted safely in this soil.

For the experiment in 1912 a plot of land was used on which gladioli had been grown for the past three years. The chemicals used and the amounts per acre were as follows: air-slaked lime, 1200 pounds; sulfur, 1000 pounds; air-slaked lime 800 pounds, and sulfur 1000 pounds; sulfate of iron, 1800 pounds; acid phosphate, 1200 pounds; acid phosphate, 2100 pounds. The chemicals were applied by the use of a lime spreader, in strips of 10 by 136 feet, a strip of equal width being left between each of the treated areas to serve as a check. The entire experiment was conducted in triplicate. Across the strips and at right angles to them were planted the rows of corms, each row consisting of a single variety. During the growing season special care was taken to see that no soil was carried from one treated area into another or into the checks. The results of the treatments were based on corms removed from a center seven-feet strip of each of the treated and the check areas.

In the following January, when the results of this experiment were recorded, it was found that none of the treatments had been of any value. No reduction whatever was obtained in the amount of disease in treated as compared with untreated corms. Since the chemicals were applied in as large amounts as is commercially practicable, if not larger, no further soil treatments with chemicals have been tried on a large scale.

Experiment 2. Formalin as a soil disinfectant.— Soil in which seedlings had been grown for the past two years was treated in 1912 with one gallon of one-per-cent formalin solution per square foot. The plot was covered with heavy burlap for two days after being treated. As soon as the odor of formaldehyde could no longer be detected, seeds were planted in the treated soil, other seeds being planted in untreated soil to serve as a check.

During the summer the hard rot disease appeared on the foliage of these seedlings. No doubt infection occurred from spores blown from diseased seedlings growing near by in untreated soil. The corms were harvested in the autumn and stored in a cool room.

In the following January, when the corms were examined, it was found that seventeen per cent of those grown in treated soil were diseased, while thirty-seven per cent of the corms from untreated soil showed disease. Since the disease appeared on the foliage of these plants during the summer, it was impossible to determine whether the source of infection was the mycelium of the fungus in the soil, or spores that might have been washed down from the leaves to the soil where they would germinate and infect the corms. Therefore it was impossible to determine from this experiment whether or not the formalin treatment had been of value as a soil disinfectant. The experiment was repeated in 1915, but no results were obtained because the seed planted failed to germinate.

Experiment 3. Formalin as a soil disinfectant.— The value of formalin as a soil disinfectant for *Septoria Gladioli* Passer. and the dry rot fungus was further tested by treating soil in which gladioli had been grown for the past two years with formalin at the rate of one gallon of one-per-cent solution per square foot. Healthy corms were planted in this soil. No lesions of the hard rot disease appeared on the foliage during the summer. In the following January, when the corms were examined, it was found that the treatment had proved of no value in reducing the percentage of disease, as compared with healthy corms growing in untreated soil. However, the treated plat was not sufficiently isolated from other untreated areas to preclude the possibility that infected soil might have been carried from untreated soil to that which was treated, and hence the results must be considered with that restriction.

SANITATION

It has been shown that the hard rot fungus is able to live over winter on dead tops left lying about on the ground. It follows that these tops should be raked up in the fall and burned. This suggestion applies particularly to the tops of seedlings and cormels, since the disease has been observed by the writer to occur on the foliage of but six plants of flowering size. It has also been indicated that the fungi causing the hard rot and dry rot diseases of gladioli will live in the soil for at least four years. Care should therefore be taken that the soil does not become infected with the pathogenes. Only healthy corms should be planted in soil which it is desired to keep free from these fungi; at least more care should be exercised at planting time to see that no corms badly diseased are planted. Such corms should be discarded and burned, for they will but decay in the soil and infect it with the disease-producing organisms. Crop rotation should be practiced.

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LEAF SMUT OF TIMOTHY

GEORGE A. OSNER

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LEAF SMUT OF TIMOTHY[1]

George A. Osner

HOSTS

Leaf smut of timothy has been reported on a large number of grasses of the subfamily Poacoideae, of the Gramineae. To give an accurate and complete list of all the hosts affected by this disease will not be possible until the morphological and biological limits of the causal organism shall have been determined by careful comparison and cross-inoculation on the various European and American hosts. The following list contains the more important hosts mentioned as subject to the disease, but the list is not claimed to be complete:

Agrostis alba L. (redtop), *Agrostis alba* var. *vulgaris* (With.) Thurb., *Agrostis stolonifera* L. (creeping bent), *Alopecurus pratensis* L. (meadow foxtail), *Ammophila arenaria* (L.) Link (beach grass), *Anthoxanthum odoratum* L. (perennial sweet vernal grass), *Arrhenatherum elatius* (L.) Beauv. (tall oat grass), *Avena pubescens* Huds., *Brachypodium pinnatum* Beauv., *Brachypodium sylvaticum* Beauv., *Briza media* L. (perennial quaking grass), *Bromus erectus* Huds., *Bromus inermis* Leyss. (Hungarian brome grass), *Dactylis glomerata* L. (orchard grass, or cocksfoot), *Deschampsia caespitosa* (L.) Beauv., *Elymus canadensis* var. *glaucifolius* (Muhl.) Gray (glaucous wild rye), *Elymus glaucus* Buck. (smooth wild rye), *Elymus robustus* Scr. & J. G. Sm., *Elymus virginicus* L. (Virginia wild rye), *Festuca distans* Kunth, *Festuca elatior* L. (meadow fescue), *Festuca nutans* Spreng. (nodding fescue), *Festuca ovina* L. (sheep's fescue), *Festuca ovina* var. *duriuscula* (L.) Hack., *Festuca ovina* var. *glauca* Hack., *Holcus lanatus* L. (velvet grass), *Holcus mollis* L., *Lolium multiflorum* Lam. (awned, or Italian, rye grass), *Lolium perenne* L. (ray grass), *Milium effusum* L. (millet grass), *Phleum pratense* L. (timothy), *Poa annua* L. (low spear grass), *Poa bulbosa* L., *Poa debilis* Torr. (weak spear grass), *Poa nemoralis* L., *Poa pratensis* L. (Kentucky bluegrass), *Poa trivialis* L. (rough-stalked meadow grass), *Sitanion longifolium* J. G. Sm. (long-bristled wild rye).

The writer has observed this disease on the following plants in New York: *Agrostis alba* var. *vulgaris* (With.) Thurb., *Agrostis alba* var. undetermined (a creeping variety), *Dactylis glomerata* L., *Phleum pratense* L., *Poa annua* L., and *Poa pratensis* L.

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[1] Also presented to the Faculty of the Graduate School of Cornell University, June, 1915, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

Author's acknowledgments. The writer wishes to acknowledge his indebtedness to Professors Donald Reddick and H. H. Whetzel, of the Department of Plant Pathology, Cornell University, for helpful suggestions and criticisms during these investigations, and to H. H. Knight for a number of the photographs that are here reproduced.

The only mention in literature of varietal susceptibility is by Clinton (1900),[2] who states that the fungus causing leaf smut is most injurious to redtop. The writer has found this true for New York. He has never found Canada bluegrass infected, altho it frequently occurs in association with diseased Kentucky bluegrass.

THE DISEASE

NAMES

The term *leaf smut of timothy*, which is employed by the writer to designate this disease, was first used in this country by Trelease (1887). The name is not entirely applicable, since the lesions are by no means limited to the leaves. However, since the lesions on the leaves constitute the most characteristic symptom, this name is retained. In Denmark the name *graessernes stinkbrand* (stinking smut of grasses) has been used, probably on the supposition that the pathogene is closely related to that of the stinking smut of wheat (Rostrup, 1904).

HISTORY AND DISTRIBUTION

The origin of this disease is unknown. It was first recorded from Italy on *Holcus mollis* by Cesati (1850). Westendorp (1852) records it from Belgium on velvet grass (*Holcus lanatus*) and perennial sweet vernal grass (*Anthoxanthum odoratum*). It has since been reported from various European countries and from Australia as being more or less common.

The first mention of the disease in North America was by Trelease (1885 a), in a paper read before the Wisconsin Academy of Science in December, 1882. He records it from Wisconsin on timothy (*Phleum pratense*) and on glaucous wild rye (*Elymus canadensis* var. *glaucifolius*). Trelease (1885 b) also published the first economic account of leaf smut, stating that it had been very prevalent in Wisconsin for the previous two seasons. Clinton (1906) gives its present distribution in North America as: California, Connecticut, Delaware, District of Columbia, Illinois, Indiana, Iowa, Kansas, Maine, Massachusetts, Minnesota, Missouri, New Jersey, New York, Ohio, Texas, Utah, Washington, Wisconsin, and Canada. The writer has observed it in several counties of New York and Indiana.

ECONOMIC IMPORTANCE

Economic loss from this disease occurs in two ways. First, thru a reduction in the yield of hay, and second, thru a reduction in the yield of seed. The fact that diseased plants are usually stunted in growth is probably the reason why the disease is so generally overlooked. Even in badly infested fields the grower is likely to attribute the reduction in yield to the weather or to other external factors.

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[2] Dates in parenthesis refer to bibliography, page 226.

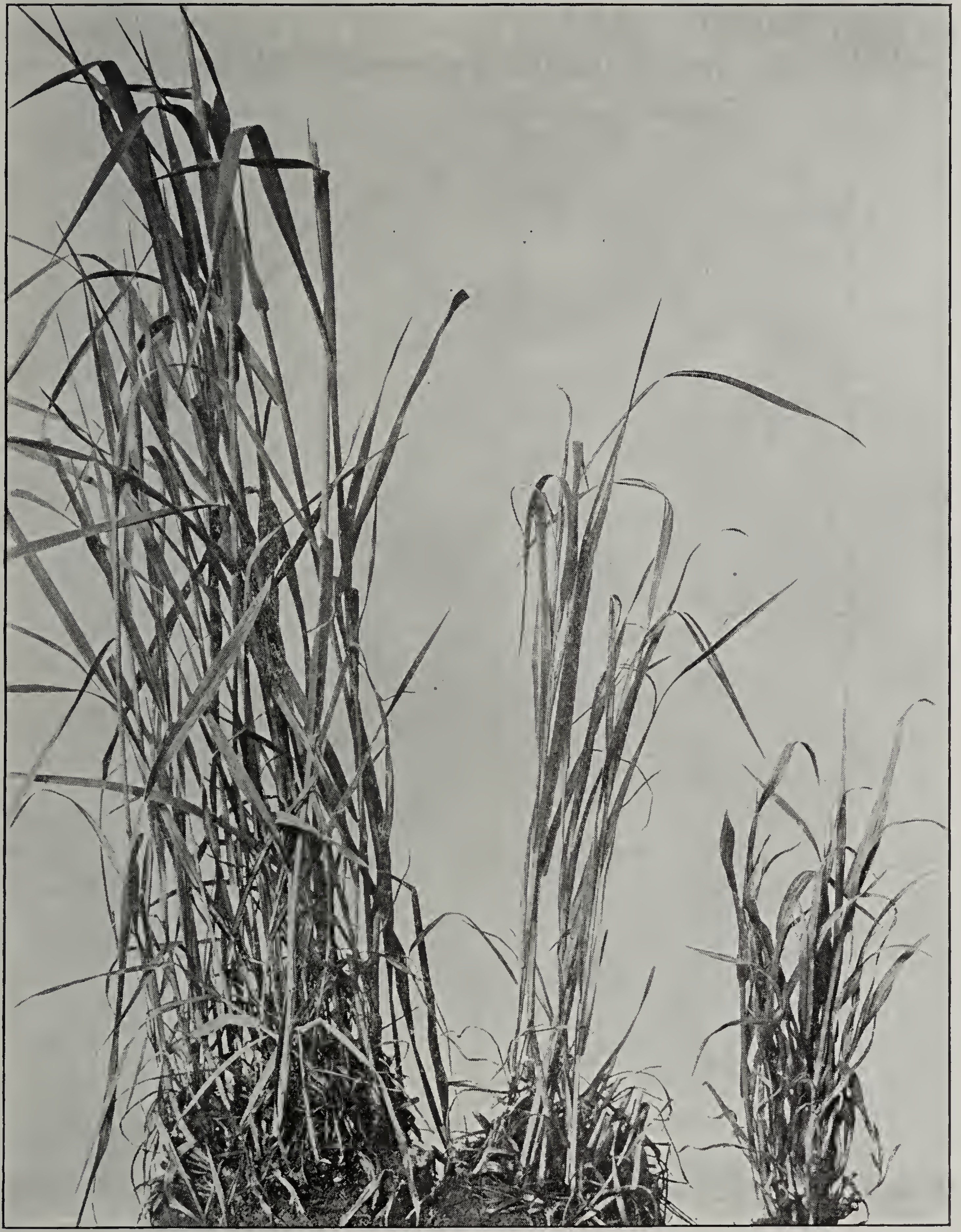


FIG. 45. LEAF SMUT ON TIMOTHY
Healthy plant (at left) contrasted with diseased, stunted plants

Several writers have reported leaf smut as causing considerable damage to meadows. Clinton (1900) says that in 1898 he found a field of redtop injured thirty per cent. The owner stated that at times the injury had cut down the yield of seed from the normal 300 hundredweight to 70 hundredweight. Pammel (1892 a) reports considerable loss on the Iowa College farm from the disease. He states (1893) that it can be found in most timothy fields. Trelease (1885 b) says the fungus caused considerable loss about Madison, Wisconsin, in 1883 and 1884. Griffiths (1903) reports damage to timothy in Jess Valley, California.

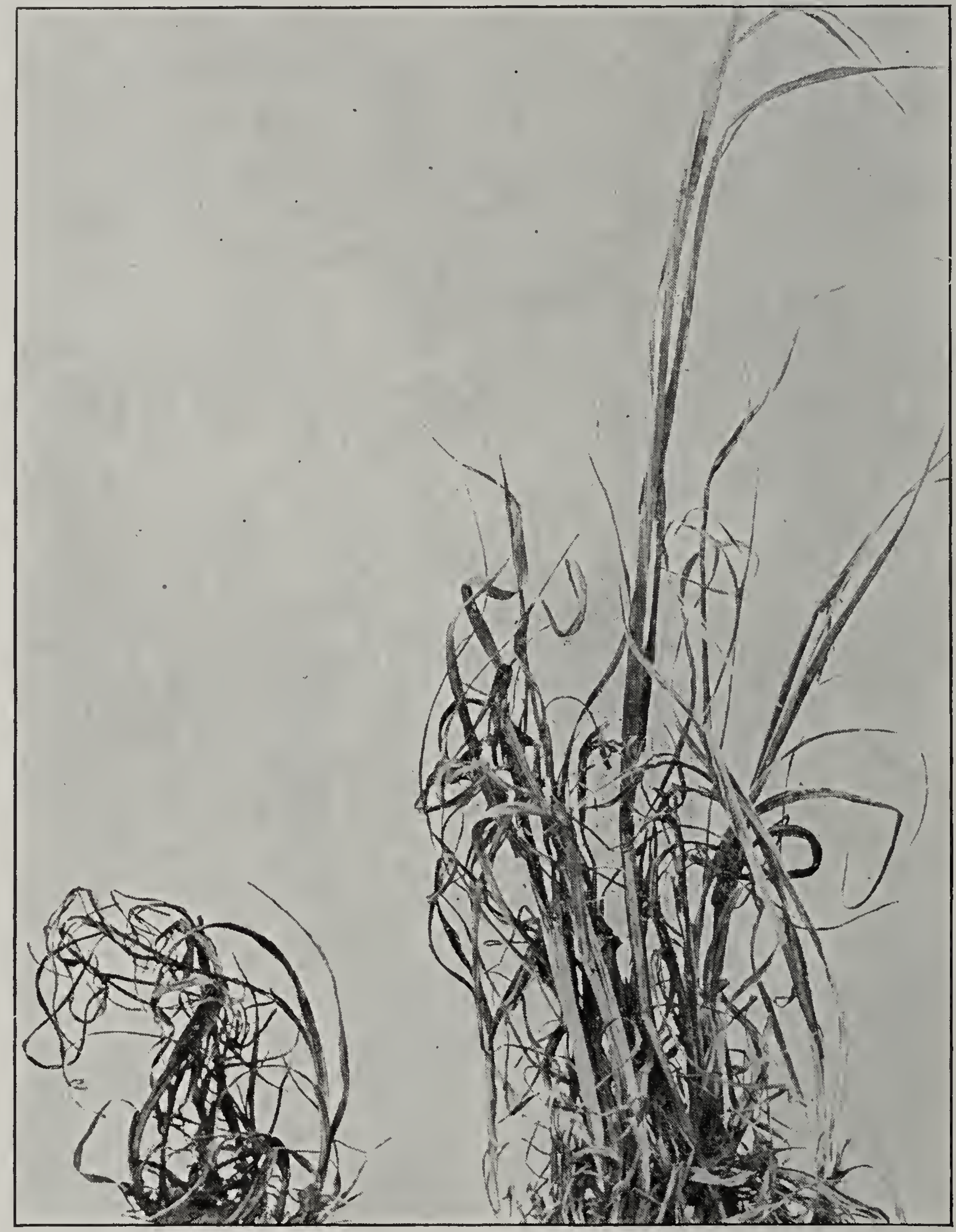


FIG. 46. TIMOTHY PLANTS KILLED BY THE LEAF SMUT FUNGUS

Leaf smut is extremely common in New York. In the summer of 1914 the writer examined a large number of timothy fields in nine counties, and found the disease in more or less abundance in every field. In one field over fifty per cent of the stools were affected. The loss of hay in this field was estimated to be about thirty per cent. If the timothy had been grown for seed the loss would have been greater. In 1914 the

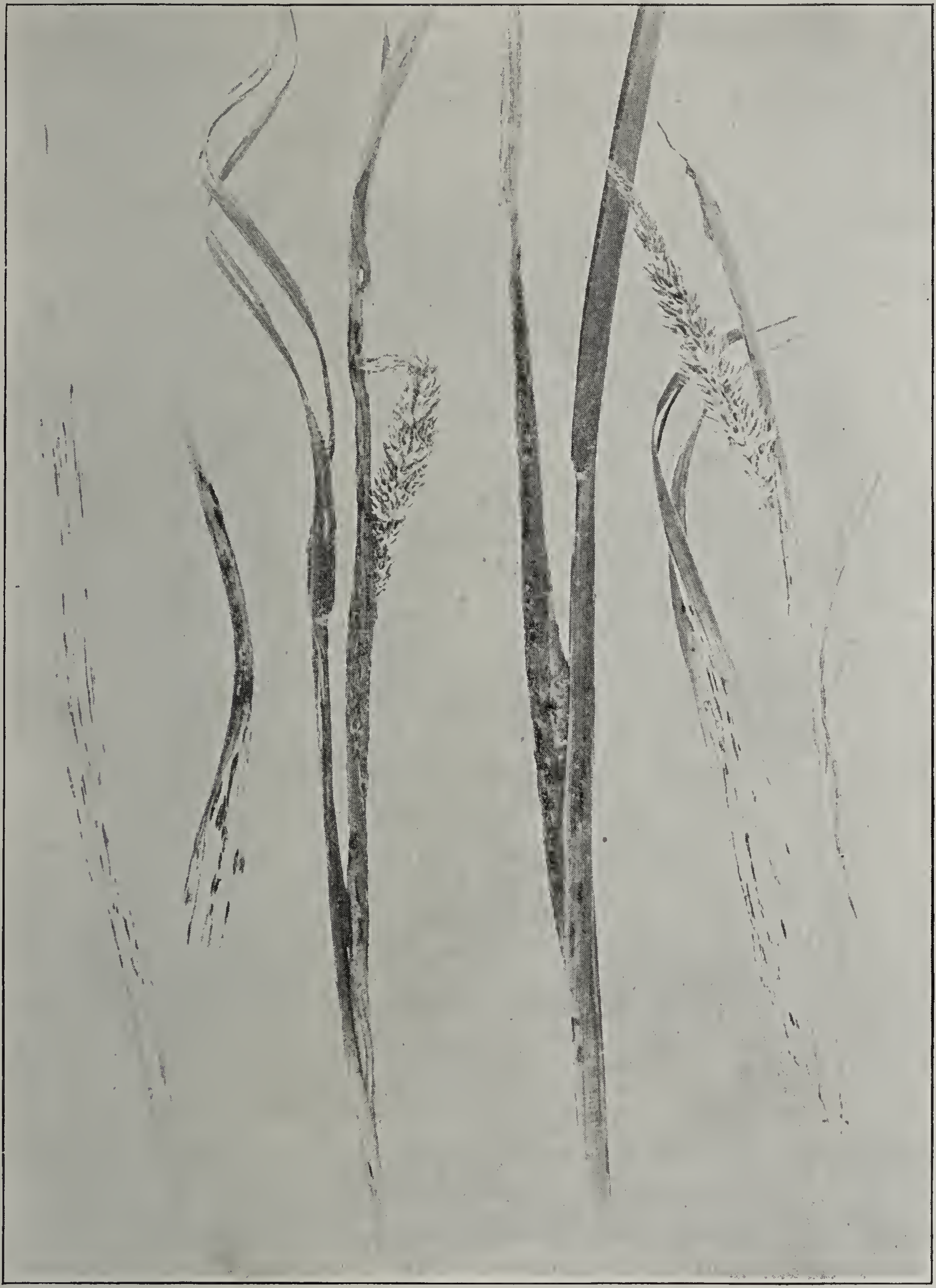


FIG. 47. LESIONS OF LEAF SMUT ON LEAVES AND INFLORESCENCE OF TIMOTHY

Leaves show the typical tearing, or shredding disease caused a reduction in the yield of hay in Genesee County of probably not far from four per cent. In other counties the writer has not examined a sufficient number of fields to be able to speak with certainty as to average losses.

SYMPTOMS

The diseased plants are usually more or less stunted (fig. 45). They may be found showing all degrees of this dwarfing, from plants not over four or five inches high and with only three or four leaves to those that are apparently equal in vigor to the healthy plants. Frequently the more diseased culms in a stool are much dwarfed, while the others are nearly normal. Later in the summer some of the smaller plants will be found to have been killed outright (fig. 46).

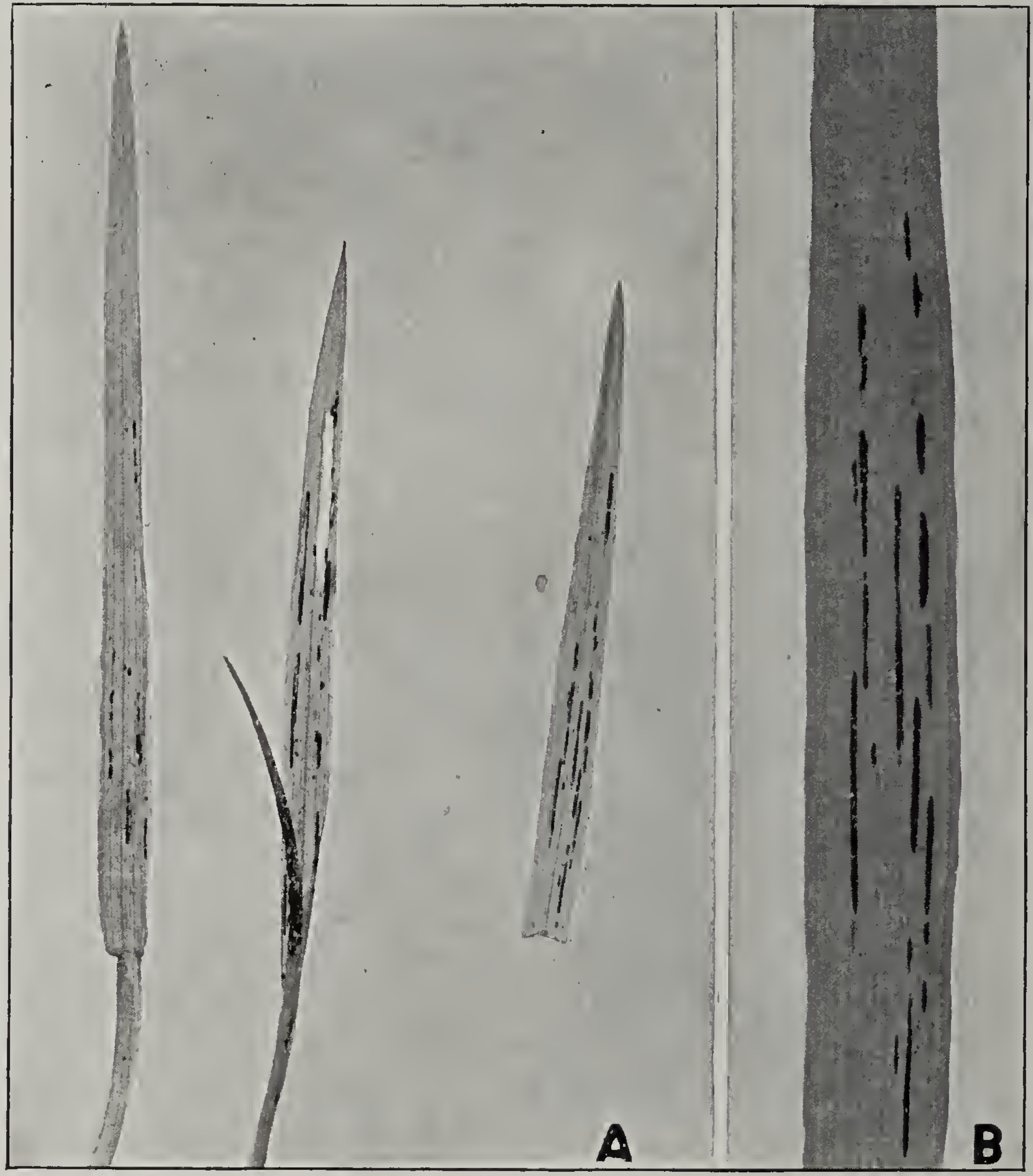


FIG. 48. SORI OF USTILAGO STRIAEFORMIS IN LEAVES OF TIMOTHY

One plant shows sori in the young unfolded leaf. The chlorophyll had been partly removed before taking the photograph. A, natural size; B, × 3

On the leaves

The disease shows first as elongate, narrow striæ on leaves and sheaths, and later appears on the stems (figs. 45, 47, and 48). In the latitude of

New York the sori do not become conspicuous until about the first of May, but on careful search they may be found any time during the winter on plants that have not been killed back entirely by frost. When first visible they may be not over one-tenth of a millimeter in width and two-tenths of a millimeter in length, but are usually from two-tenths to four-tenths of a millimeter in width by from one-half to one millimeter or more in length. Later, by fusion of the sori end to end, they may become several centimeters long or may even extend thruout the length of the leaf and down the sheath. Occasionally the sori may also fuse laterally. The number of sori on a leaf may vary from one to several, in some cases nearly the whole surface of the leaf being covered.

At first the sorus may be visible on only one surface, depending on whether it originates nearer the upper or the lower epidermis. Later it usually extends thru the leaf from surface to surface, being covered only by the epidermis, which gives it a lead-colored appearance. As the spores mature, the sorus increases in size, pushing up the epidermis one-tenth of a millimeter or more (Plate XVII, 6). Later the epidermis ruptures, exposing the dark brown or nearly black, dusty mass of spores beneath. These spores are scattered by the wind and the leaves become very much torn and shredded (fig. 47). This shredded appearance of the leaves is one of the most striking symptoms on the older plants, enabling one to recognize the disease at a considerable distance. As the leaves push out at the tip of the growing plant, the lead-colored sori are often found already present (fig. 48, A), and in badly diseased plants these sori may extend down to the base of the stem. If the stem is cut across a short distance back of the growing tip, the black spore masses may be found in the outer cortex (Plate XVII, 4).

There is usually little or no difference in color between diseased and healthy plants, unless the leaves become so badly diseased that the tissues between the sori die; in such cases the leaves become yellow or brownish.

The symptoms of the disease on the leaves of other grasses observed are very similar to those on timothy. On redtop, however, the tendency to form sori extending thruout the length of the leaf and down the sheath is much more pronounced than on timothy. The most striking characteristic of the disease on redtop is the tendency of the leaves at the top to become badly shredded (fig. 49). Its dwarfing effect on Kentucky bluegrass and on orchard grass is well shown in figures 50 and 51, respectively. In the case of Kentucky bluegrass, especially, the diseased plants are very easily overlooked because of their small size.

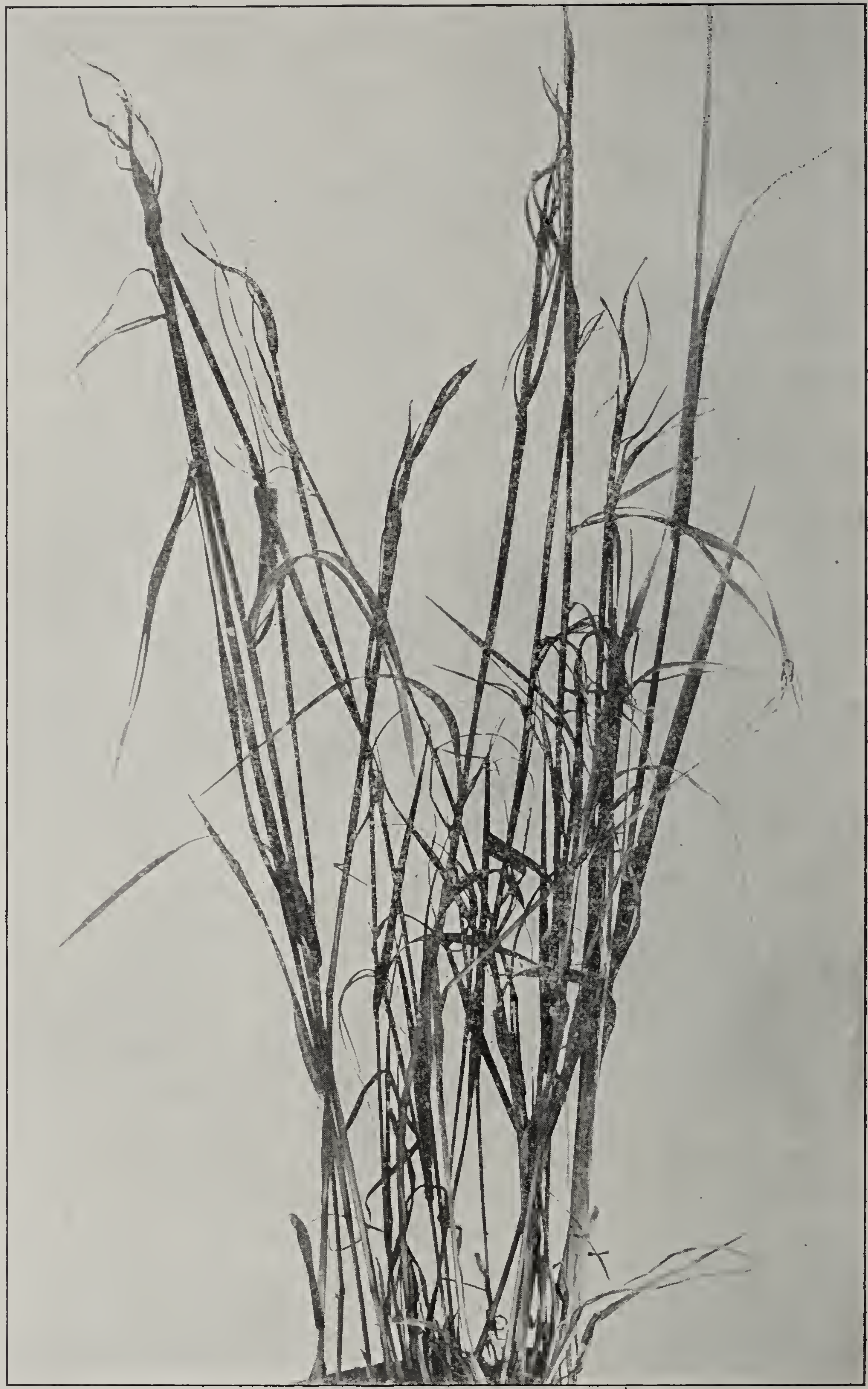


FIG. 49. LEAF SMUT ON REDTOP, SHOWING LEAVES AT THE TOP BADLY SHREDDED

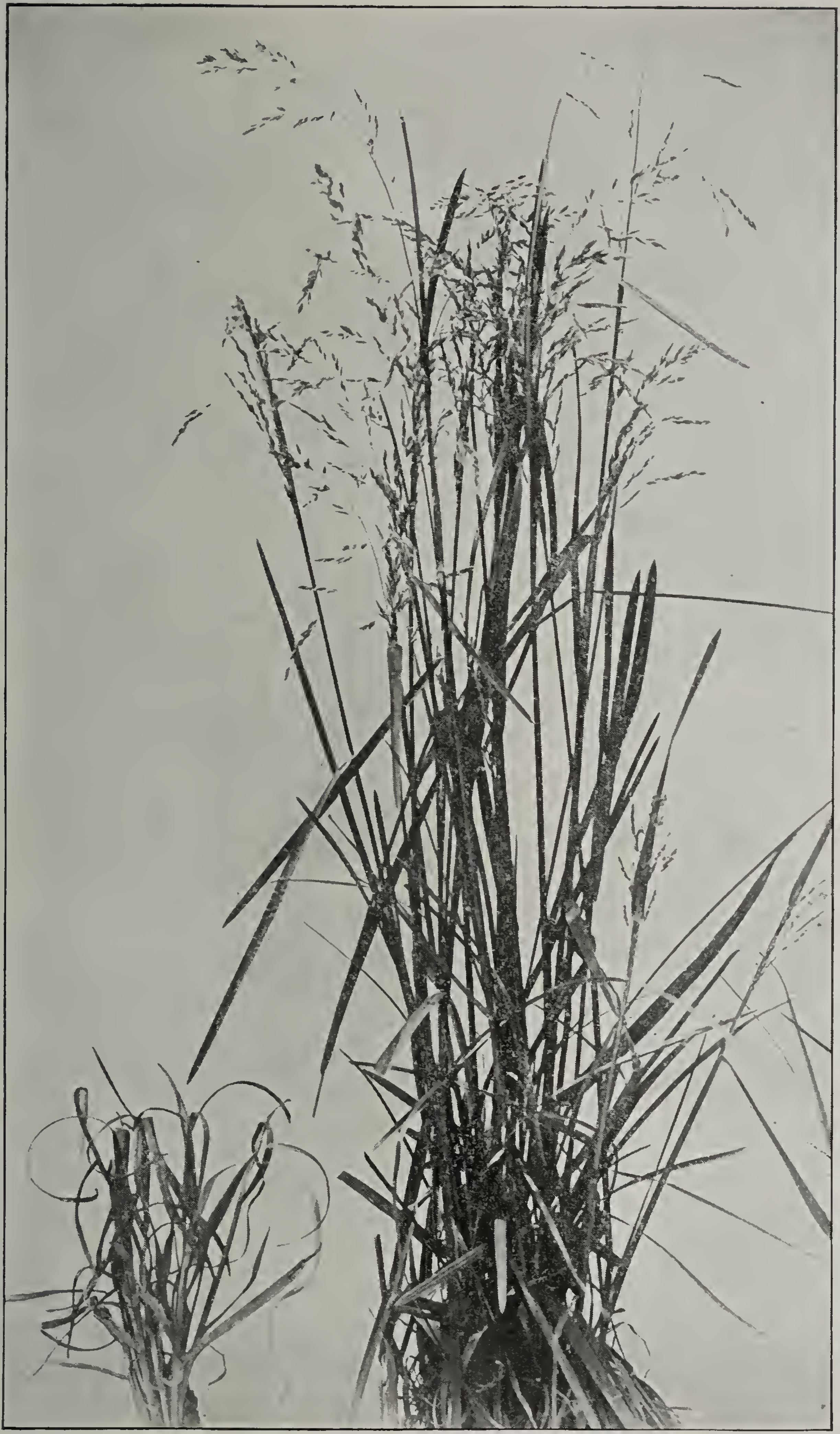


FIG. 50. LEAF SMUT ON KENTUCKY BLUEGRASS
Healthy plant (at right) contrasted with diseased, stunted plant

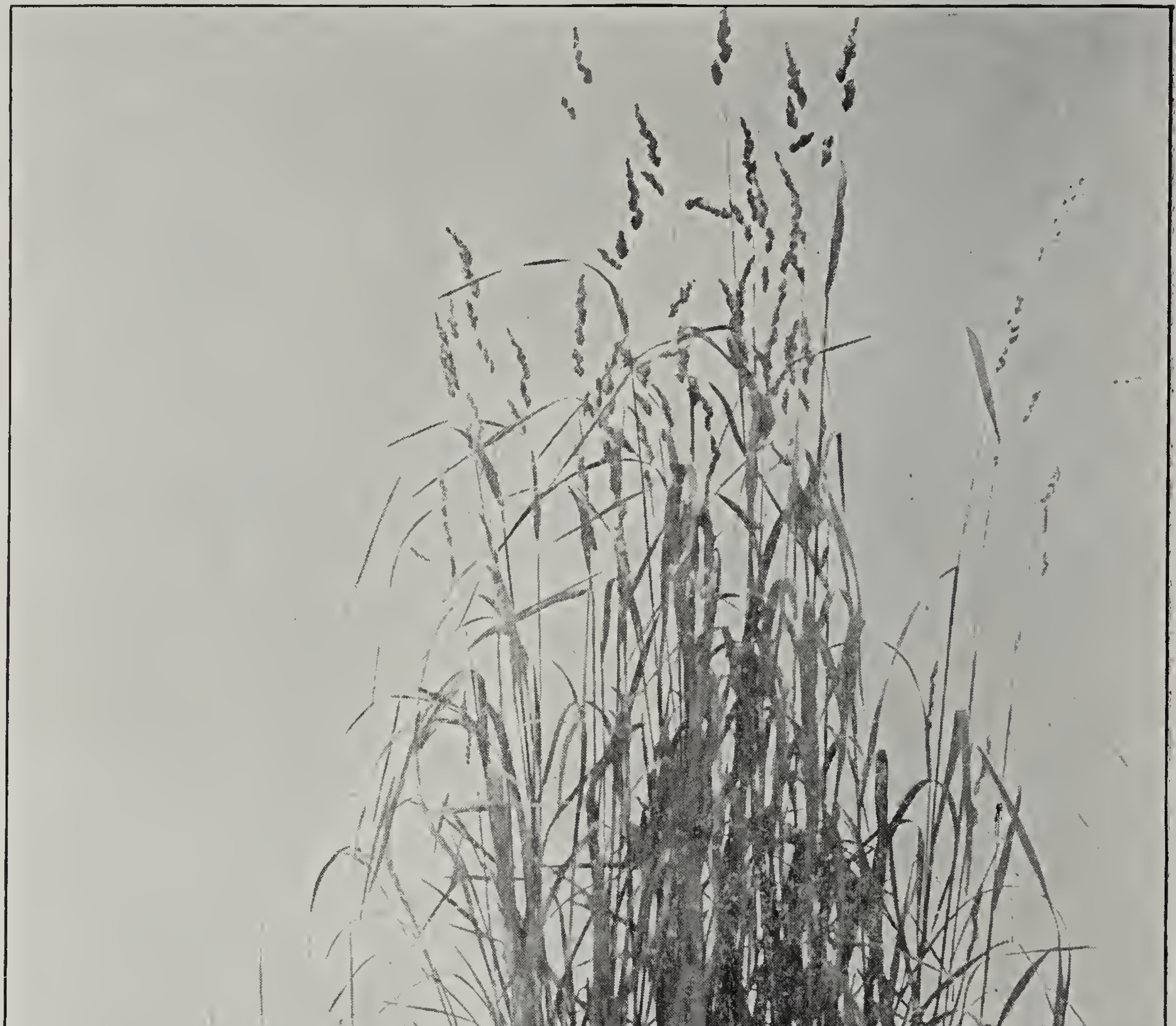


FIG. 51. LEAF SMUT ON ORCHARD GRASS
Healthy plant at right. (Photograph taken in the field)

On the inflorescence

Usually the diseased plants do not fruit. On those that do, the sori appear at an early stage as more or less elongated striæ on the rhachis or in the florets (fig. 47). In the florets any or all of the parts may be broken down and replaced by the spore mass (fig. 52). In severe attacks all parts, even including the bristles, may be destroyed. The sorus may be produced either before or after the glumes have attained nearly full growth, and in the latter case usually only a part of the glume is destroyed.

The inflorescence of redtop is usually diseased at the time it emerges from its sheath, and only rarely do diseased plants produce viable seed. Of the various hosts observed, viable seed is produced on diseased orchard grass oftener than on any other.

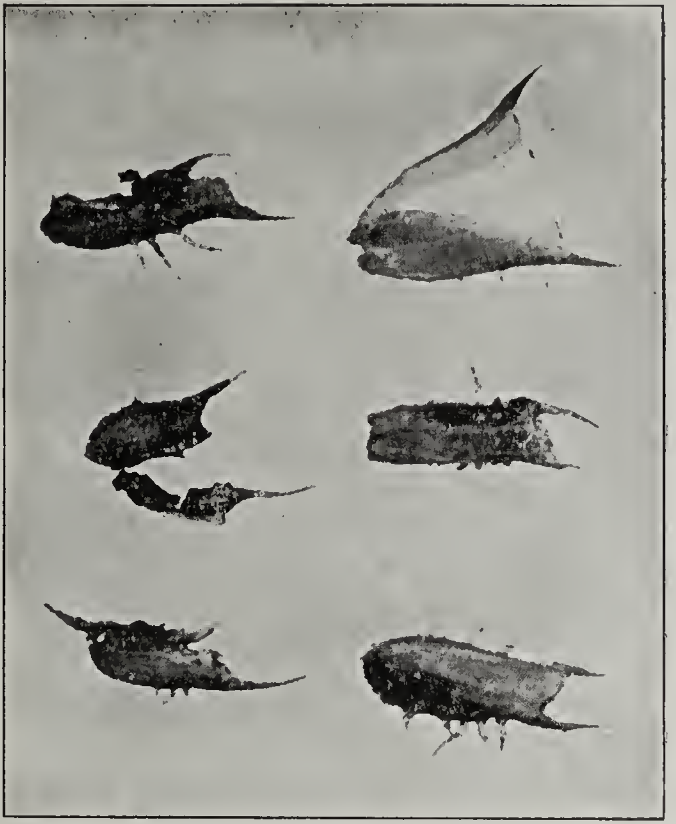


Fig. 52. HEALTHY AND DISEASED TIMOTHY SEED AND GLUMES

Healthy seed in top row at right. The seed in the smutted glumes has been destroyed. All taken from the same inflorescence. × 7

ETIOLOGY

History and classification of the pathogene

The organism causing leaf smut has been collected and described, under a number of different names, by various investigators. This is due in large measure to the fact that it occurs on such a wide range of host plants. It was first collected by Cesati on *Holcus mollis* and distributed in Klotzsch-Rabenhorst's *Herbarium Vivum Mycologicum* (1850) as *Uredo longissima* var. *Holci*. Westendorp (1852) described it from *Holcus lanatus* as a new species, giving it the name *Uredo striaeformis*, probably adopting this name because of the characteristic appearance of the lesions on leaves and stem. Fischer von Waldheim (1866) described this fungus from *Holcus mollis* as *Tilletia de Baryana*. He placed it in the genus Tilletia largely on the basis of its method of spore formation, which he reported to be on the ends of side branches. Most European mycologists have since followed this worker, placing the fungus in the genus Tilletia. Oudemans (1878) pointed out that, adopting the first specific name applied to the organism, it should be called *Tilletia striaeformis*. Niessl (1876), believing that the fungus was a species of Ustilago rather than of Tilletia, stated that it should be called *Ustilago*

PLATE XVII. PHOTOMICROGRAPHS OF MYCELIUM AND SORI OF USTILAGO STRIAEFORMIS

1, Cross section through base of a timothy stem, showing intracellular mycelium. × 700

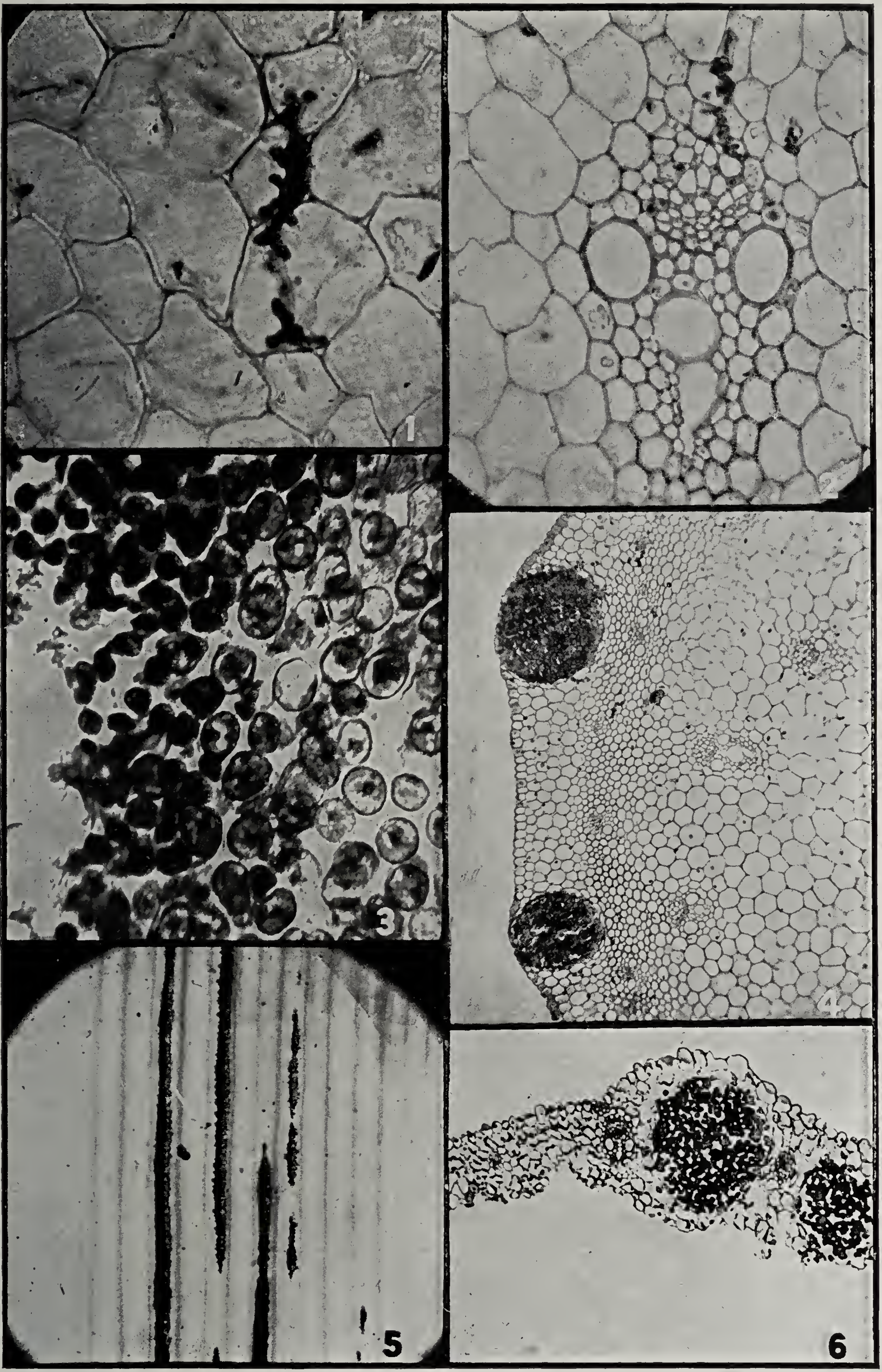
2, Cross section through base of a timothy stem, showing mycelium in a vascular bundle. × 315

3, Part of a sorus from a stem of *Dactylis glomerata*, showing large spores in the center, and smaller, less mature ones at the edge. × 560

4, Cross section of timothy stem, showing two sori in the outer cortex just beneath the epidermis. The ring of heavy-walled sclerenchyma cells containing isolated strands of mycelium is shown just inside these sori. × 75

5, Part of redtop leaf showing sori of various ages between the vascular bundles. Some of the sori are in process of fusing. × 65

6, Cross section of timothy leaf, showing two sori. The epidermal cells are hypertrophied and considerably bulged. × 75



PHOTOMICROGRAPHS OF MYCELIUM AND SORI OF USTILAGO STRIAEFORMIS

striaeformis (West.). Sporidia of this fungus, with the exception of a rather unsatisfactory figure by Pammel, Weems, and Lamson-Scribner (1901), have never been described; consequently the generic name can be determined only indirectly. The writer has adopted the name *Ustilago striaeformis* (West.) Niessl, basing his decision on the method of spore formation and spore germination as stated elsewhere (page 209).

A number of closely related species have been described, some of which may eventually prove to be identical with this fungus. Among those that apparently are distinct may be mentioned *Ustilago Salveii* Berk. & Br., *Ustilago macrospora* Desm., and *Ustilago Calamagrostidis* (Fckl.) Clinton.

A list of the more important names applied to this fungus is as follows:

Uredo longissima var. *Holci* Ces.
Klotz.-Raben. Herb. viv. mycol., no. 1498. 1850.
Uredo striaeformis West.
Acad. Roy. Belgique. Bul. **18**, ser. 2:406. 1852.
Uredo longissima var. *megalospora* Riess
Klotz.-Raben. Herb. viv. mycol., no. 1897. 1854.
Tilletia de Baryana F. de W.
Raben. Fungi eur., no. 1097. 1866.
Tilletia Milii Fckl.
Symb. myc. 1:40. 1869.
Ustilago striaeformis (West.)
Niessl in Hedwigia **15**:1. 1876.
Tilletia striaeformis
Oudemans in Bot. Ztg. **36**:440. 1878.
Tilletia striaeformis (Westd.)
Winter in Krypt.-Flora. Pilze 1^1:108. 1880.
Tilletia alopecurivora Ule
Bot. Ver. Prov. Brandenburg. Verh. **25**:214. 1884.
Tilletia Brizae Ule
Bot. Ver. Prov. Brandenburg. Verh. **25**:214. 1884.
Tilletia striiformis (Westend.) Magnus
Saccardo in Syll. fung. 7^2:484. 1888.
Ustilago poarum McAlp.
Roy. Soc. Victoria. Proc. n. ser. **7**:220. 1894.
Ustilago Washingtoniana Ell. & Ev.
Bul. Torr. Bot. Club **22**:57. 1895.
Tilletia airae-cespitosae Lindr.
Soc. pro Fauna et Flora Fennica. Acta **26**:15. 1904.

Morphological and life history studies

Spores[3]

Morphology.—The spores of this fungus vary from spherical to ellipsoidal or irregular. In sori in which the spores are not greatly crowded most of them are nearly spherical, while in sori in which much pressure has occurred the spores are found to be very irregular in shape (Plate XVII, 3). In mass they are nearly black, but as seen under the microscope they are olive-brown in color.

The spores measure from 10 to 17 μ by from 8 to 12 μ; but out of several hundred spores measured from the various hosts observed, the writer has found the majority to fall within the limits 10 to 14 μ by 8.5 to 11 μ. The spore is covered with a thick wall, which is divided into two layers—a hyaline inner endospore and a darker, thicker exospore (fig. 53, E). The latter varies from echinulate to verrucose, even in viable spores from the same plant. These spines or warts are usually rather blunt, and on mature spores (fig. 53, D, E) are about one micron in length. They may be close together or may stand a considerable distance apart. The endospore is difficult to discern in fresh spores, but becomes more readily apparent if the spore is held for a few minutes in dilute sulfuric acid. The spores contain large oil globules, which are usually more readily seen

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[3] The term *spore* is used thruout this paper in preference to the word *chlamydospore*.

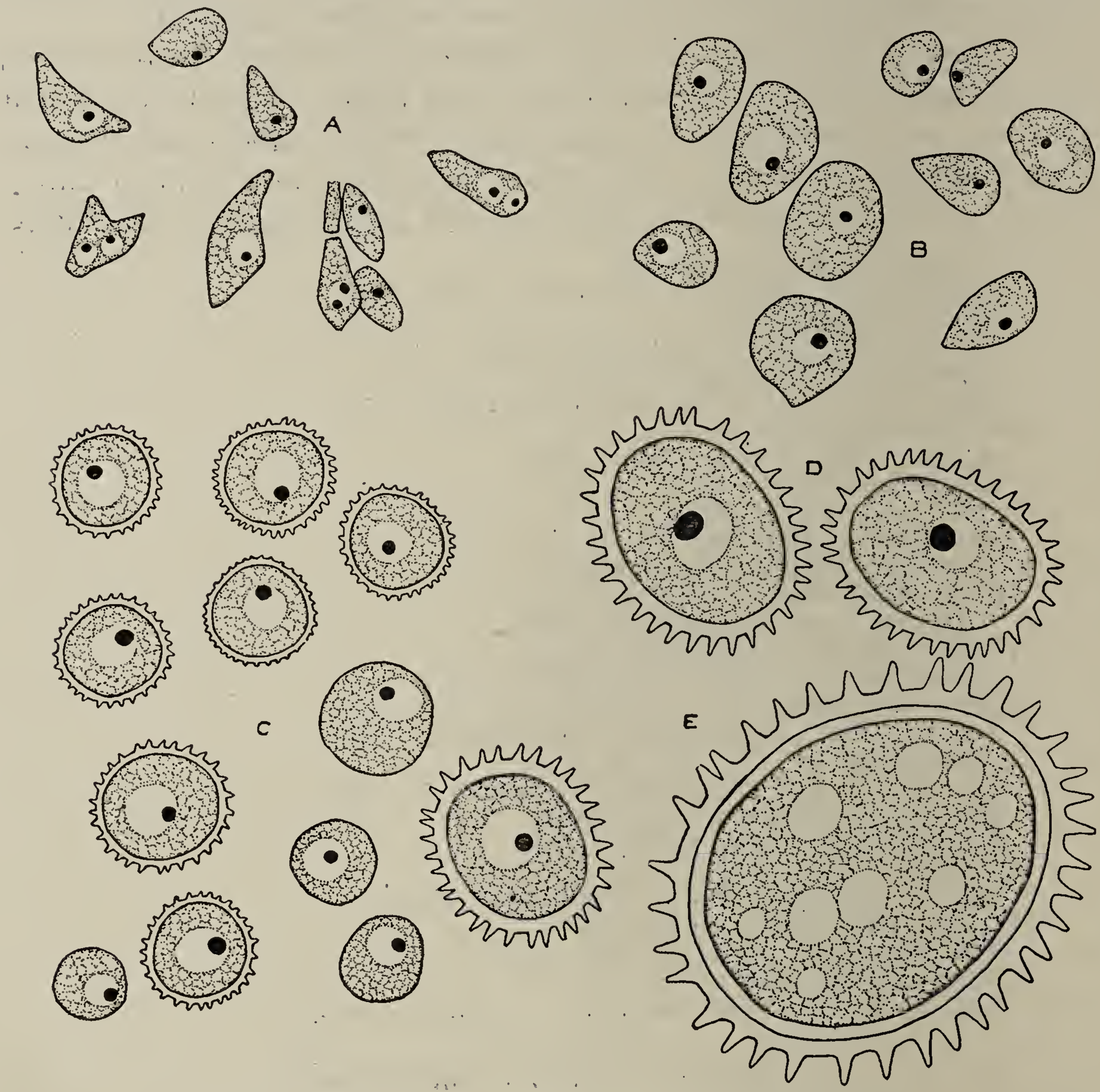

FIG. 53. SPORE FORMATION OF USTILAGO STRIAEFORMIS

A, Immature spores from *Dactylis glomerata*, showing various stages in the fusion of the nuclei. In two spores the nuclei are not yet fused. One spore has a single nucleus with the nucleoli not yet fused. × 1670

B, C, Various stages in the maturation of spores from *Dactylis glomerata*. × 1670

D, Mature spores from *Dactylis glomerata*. × 1670

E, Mature spore from timothy, showing endospore and vacuoles, or oil globules. × 3530 after treatment with dilute potassium hydroxide solution. The mature spores each have a single nucleus, varying from 2.5 to 5.5μ in diameter. Each nucleus has a single large nucleolus.

Germination.[4]—In literature only a few investigators have reported germination of the spores of this fungus. Pammel (1893) says the spores germinate readily. Pammel, Weems, and Lamson-Scribner (1901) report that the spores germinate like those of *Tilletia Tritici.* They figure one germinating spore and a small promycelium with sporidia at the end, not, however, attached to a spore. Clinton (1900) figures germinating spores of this fungus from redtop. He says the germ tube branched but did not form sporidia. The contents were mostly at the tip of the germ tube. A number of writers (Saccardo 1888, Plowright 1889, Schroeter 1889, Brocq-Rousseu et Gain 1910, and Schellenberg 1911) report that Fischer von Waldheim observed germination analogous to that of *Tilletia Tritici.* This impression has apparently arisen from his statement (Fischer von Waldheim, 1866), "Cum *Tilletia Carie* sporarum evolutione congruit." As was pointed out by Oudemans (1893), this statement had reference to the production of spores in the mycelium and not to their germination, since later (1869-70:125) Fischer von Waldheim says: "Ungeachtet vielfach wiederholter Versuche gelang es mir nicht die Sporen von *Tilletia endophylla*, *de Baryana*, ... zum Keimen zu bringen."

In germination studies with this fungus the writer has used a considerable number of substrata, among which may be mentioned the following: distilled water, tap water, Richard's full-nutrient solution[5] (using potassium nitrate and ferric chloride in place of ammonium nitrate and ferrous sulfate, respectively), Cohn's modified solution,[6] manure extract solution and agar,[7] soil extract solution and agar,[8] hay infusion, extract from germinated timothy and redtop seedlings, extract from timothy and redtop flowers, moist filter paper, acetic acid solution 0.02 per cent, dilute solutions of ammonium hydroxide, ether, copper sulfate, calcium chloride, sulfuric acid, potassium permanganate.

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[4] The following methods were used in staining spores and germ tubes: The germinated spores were transferred to slides coated with egg albumen. The drop or drops were allowed to concentrate as much as possible without drying, and two or three drops of fixer, usually Flemming's weaker solution, were added. After allowing this to concentrate, the slide was passed thru grades of alcohol up to ninety-five per cent, and after bringing back to a weaker alcohol or to water it was then stained with either Flemming's triple stain or Heidenhain's iron-haematoxylin. In some cases the spores were germinated directly on the slide coated with egg albumen and fixed without transferring. Occasionally the spores were germinated on a very thin film of agar on a glass slide. This film of agar, with the germinated spores, was then fixed and stained. However, the agar was so quickly covered by foreign organisms that the method was of little value. The writer has not succeeded in obtaining viable spores free from bacteria or other fungi.

The material for examination of mycelium and spore formation was fixed in Flemming's weaker solution or in chromo-acetic acid solution. When the material was not too thick, no trouble was experienced in securing penetration of the fixing solution. For staining, Flemming's triple stain, Heidenhain's iron-haematoxylin, and Mayer's haemalum were used. As counter stains, orange G, eosin, and light green were employed either in aqueous solution or in clove oil. In some cases Heidenhain's iron-haematoxylin and Mayer's haemalum were combined. In this combination the iron-haematoxylin stains the nuclei while the haemalum stains the gelatinous sheath.

[5] Richards, H. M. Jahrb. wiss. Bot. [Pringsheim] 30:667. 1897.

[6] Kellerman, W. A., and Swingle, W. T. Kansas Agr. Exp. Sta. Rept. 2:229-231. 1890.

[7] Jensen, C. N. Cornell Univ. Agr. Exp. Sta. Bul. 315:431-432. 1912.

[8] Jensen, C. N. Cornell Univ. Agr. Exp. Sta. Bul. 315:430-431. 1912.

Two methods for obtaining spore germination were used. In the first, the spores were placed in drops of the solution on slides supported in petri dishes. To prevent evaporation, the bottom of each petri dish was covered with water or with some of the liquid to be tested. In the second method, the spores were allowed to dry on the cover glass and were then covered with a drop of agar, thus bringing the spores nearer the cover glass for examination.

In the spring of 1914 the writer obtained a small percentage of germination in a one-tenth-per-cent ether solution of spores taken from diseased timothy plants in the greenhouse. He has since made repeated attempts to germinate fresh spores both from these plants and from other timothy plants, but only an occasional spore has germinated. A considerable quantity of material was also collected, part of which was kept in the laboratory and part placed in wire netting outside. From time to time during the fall, winter, and succeeding summer, attempts were made to germinate these spores, but without success. A small percentage of germination has been obtained two or three times with spores from Kentucky bluegrass.

Much better germination has been obtained with spores from redtop, in one instance over ninety per cent of the spores germinating. The proper conditions for spore germination have not been determined, but, as shown by the following observations, spores seem to retain their vitality longer if kept in a moist atmosphere. In the above-mentioned case of ninety per cent germination, the spores were taken from what appeared to be rather young sori — that is, the epidermis was still intact or had just been ruptured. The plants had been brought into the laboratory and placed in a moist chamber above water. Spores taken from these plants twenty-four hours later showed about twenty per cent germination, and after forty-eight hours no further germination was observed. In another case plants were brought into the laboratory, and fresh spores taken from them and placed under favorable conditions germinated to the extent of fifteen per cent. Half the plants were placed in a moist chamber above water, while the others were left in the open laboratory. The next day spores from the plants in the moist chamber showed about four per cent germination, while all those taken from the plants left exposed failed to germinate. Similar results have later been obtained at different times. As will be shown later, the age of spores in a single sorus varies considerably, so that it is not possible to tell with certainty the age of spores that may germinate. The writer has never germinated any spores taken from sori that he knew to be very old.

The manner or the abundance of spore germination does not seem to be affected by the medium in which the spores are placed. While the writer has found considerable variation in the germination of different lots of spores, this variation occurred more or less in all the media employed.

The usual method of germination is for the germ tube to push out thru a hole that it makes in the spore wall. In some cases the wall cracks, due to the pressure exerted (fig. 54, O). After the contents of the spore have passed out, the crack is nearly closed. The germ tube continues to elongate, the contents of the spore becoming vacuolate (fig. 54, B-E). At about the time the germ tube is put forth, the large nucleus in the spore divides (fig. 54, A). Actual mitotic figures were not observed, but apparently four nuclei are produced in the spore before migration into the tube. In figure 54, B and C, there are three nuclei in the tube with one still remaining in the spore. These nuclei are considerably smaller than the mother nucleus. They are usually more or less ellipsoidal and not over two microns in their longest diameter. Each has a single, rather large, deeply staining nucleolus located usually near the periphery of the nucleus. These nuclei pass out with the contents of the spore and are usually found grouped closely together in the germ tube (fig. 54, F-J). By the time the germ tube has reached a length of from fifty to one hundred microns, the entire content of the spore has passed into it, leaving a clear space behind (fig. 54, F, P, and fig. 55, A, B). The protoplasm at the end of the tube nearest the spore is usually much vacuolated (fig. 54, Q, R, and fig. 55, A, B). With continued growth of the tube, the protoplasmic content, with the four nuclei, is found always at the growing tip (fig. 54, I-K, S, and fig. 55, A, B). From time to time hyaline cross-walls are laid down behind the protoplasm. These walls consist apparently of dried hyaloplasm. They originate at the rear of large vacuoles.

In the majority of cases growth continues in this manner indefinitely, the protoplasmic content, with the nuclei, continuing at the tip. The germ tubes may pass out of the water or other medium and grow for a considerable distance across the slide. They seem to grow equally well whether immersed in the liquid or on the surface. In many cases side branches are pushed forth by the germ tube, the protoplasmic content filling both the tip and the side branches. In most of these instances the protoplasm eventually withdraws from the side branch and continues in the tip, or withdraws from the tip and passes into the side branch (fig. 55, B). Occasionally the protoplasm becomes much vacuolated between the tip and the side branch, and later separates at one of the largest vacuoles, one half continuing in the tip and the other passing into the side branch (fig. 54, M, N, and fig. 55, A). In some cases the germ tubes become exceedingly branched, as shown in figure 54, L–N. The nuclear phenomena in these branched germ tubes were not studied.

Fig. 54. GERMINATION OF SPORES OF USTILAGO STRIAEFORMIS

The spores were taken from redtop, with the exception of those in H, I, J, and O, which were taken from Kentucky bluegrass. The spores were germinated in either tap water or distilled water.

A, Early stage of spore germination, showing the binucleate condition. Both the exospore and the endospore are visible. × 1250

B–F, Later stages of germination, showing the passage of the nuclei and the protoplasmic contents into the germ tube. × 1250

G–J, Late germination stages, showing the protoplasm and the nuclei in the tip of the germ tube. The nuclei remain grouped near together. In H and J the empty tubes at the base have collapsed in places and have stained dark. × 1250

K, Germinated spore after 72 hours. × 325

L–N, Germinated spores, showing irregular branching of germ tubes and division of protoplasmic contents into two parts. × 350

O, germinated spore, showing crack in the spore wall. × 735

P–S, Various stages in the germination of a single spore. Drawings made after 10 hours, 16 hours, 18 hours, and 48 hours, respectively. × 735

T–W, Germinated spores, showing septa and clamp connections. Drawing from a culture 48 hours old. × 735

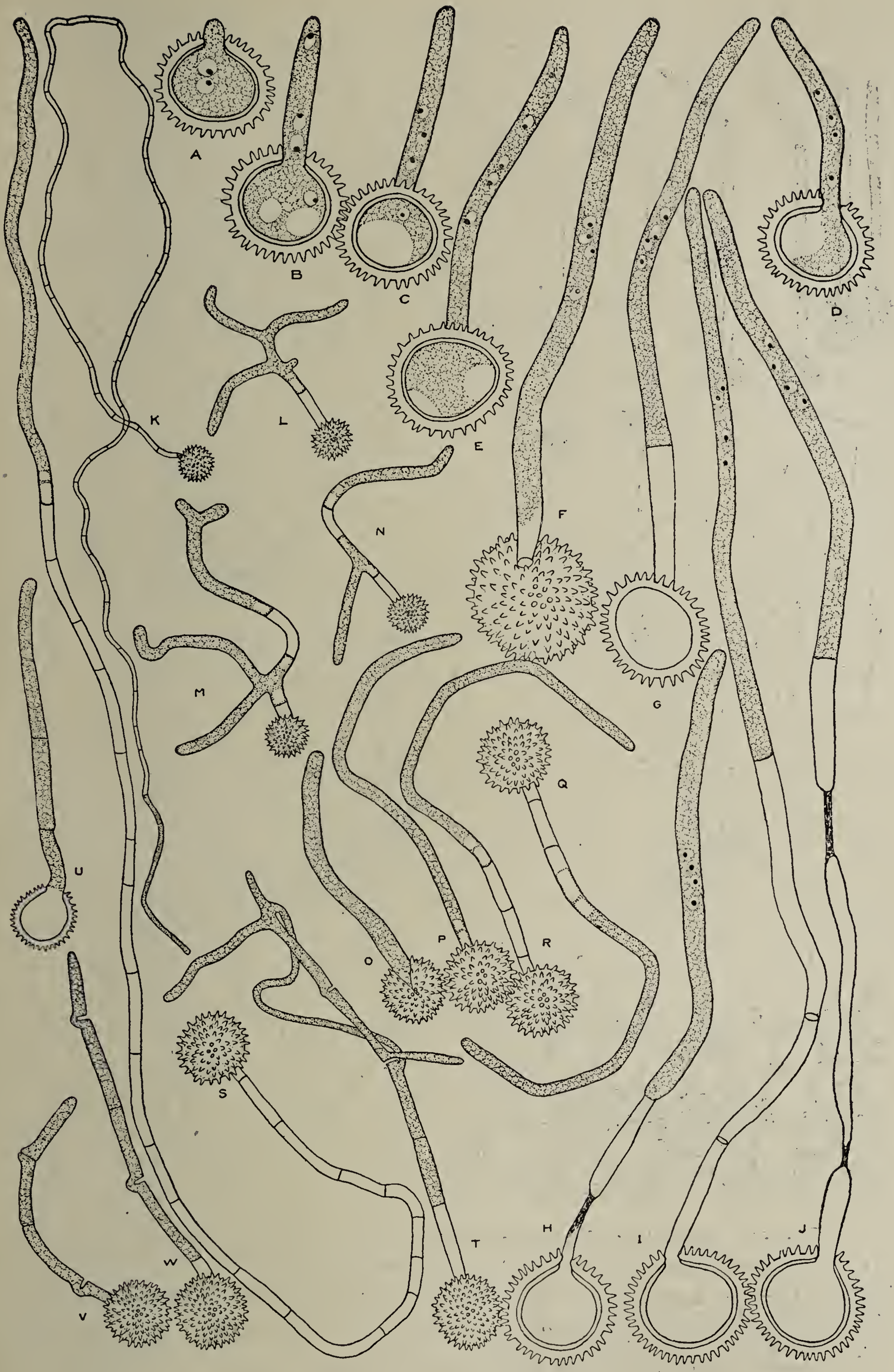

FIG. 54. GERMINATION OF SPORES OF USTILAGO STRIAEFORMIS

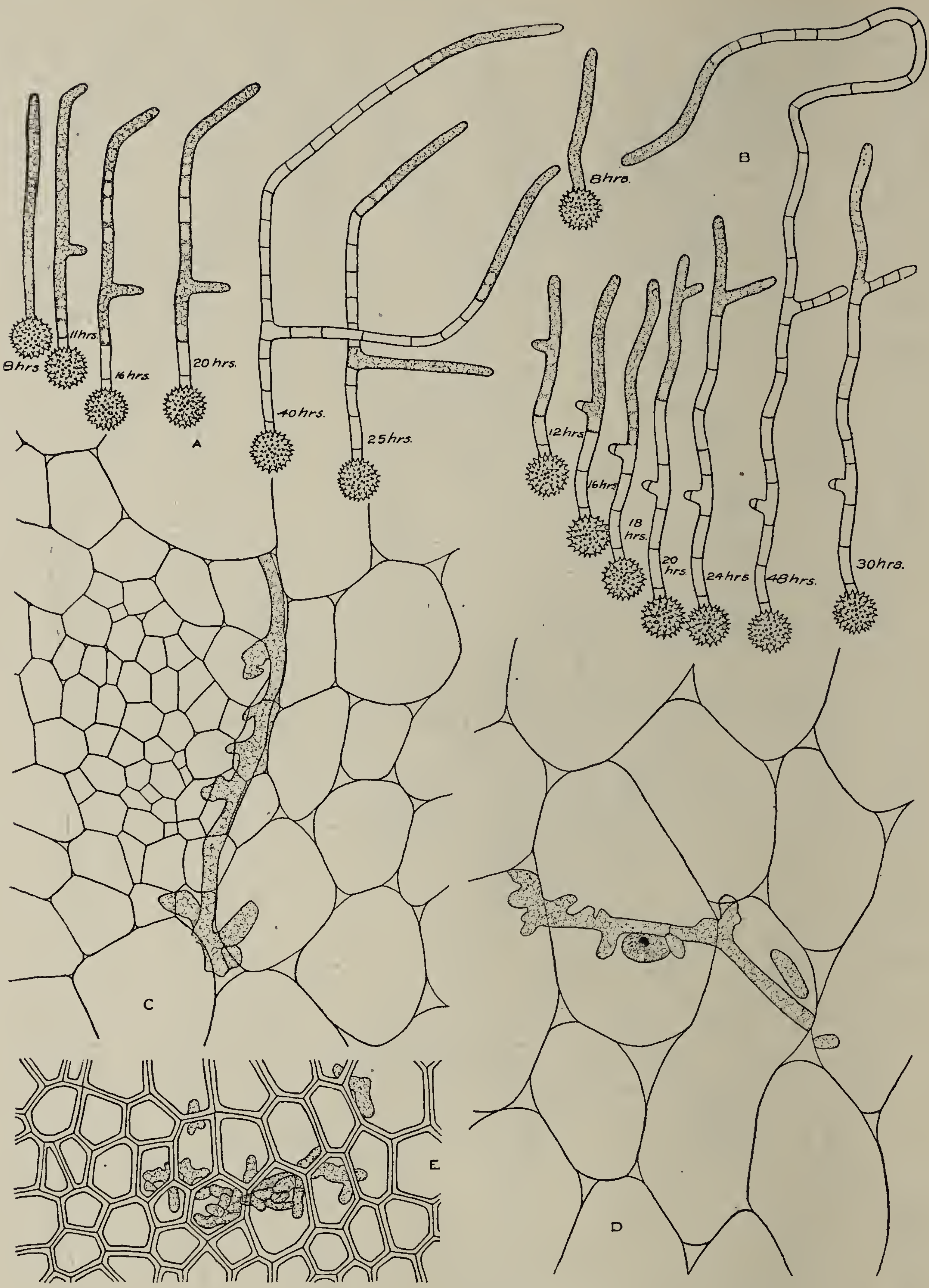

FIG. 55. MYCELIUM AND SPORE GERMINATION OF USTILAGO STRIAEFORMIS

A, Germination in distilled water of a spore from redtop, showing division of protoplasm into two parts. × 350

B, Germination in distilled water of a spore from redtop, showing formation of side branches without division of protoplasm. × 350

C, Intercellular mycelium in a timothy stem. The mycelium appears to pass thru the cells, but is merely applied closely to the cell walls. × 715

D, Intracellular mycelium in base of a timothy stem. It is applied closely to the cell nucleus. × 715

E, Intracellular mycelium in a vascular bundle of a timothy stem. × 715

In one lot of spores collected on October 5, 1914, a radically different method of germination was observed in the case of a few spores. These spores were placed in drops of water on slides in petri dishes. When examined again forty-eight hours later, the germ tubes or promycelia from a few spores on two of the slides were found to be septate, with well-developed clamp connections (fig. 54, U–W). In one case three cells were united by the clamp connections (fig. 54, T). One of the object slides was set aside to observe further development of the promycelia, while the spores on the other object slide were transferred to a slide coated with egg albumen and stained according to the method already described. Unfortunately none of the septate promycelia adhered to the slide. Further development of the promycelia on the slide set aside was apparently arrested by the strong light of the microscope, and the culture soon became contaminated with yeasts and other organisms. These spores appeared in all respects like the normal spores found on redtop. The diseased plants were collected in a meadow and were wrapped in paper before being brought to the laboratory. The spores were then taken from the sori with a flamed scalpel, and therefore it was hardly possible that there was contamination of spores from any other species of Ustilago. This production of cross-walls adds weight to the contention that the fungus is a member of the genus Ustilago, even tho no conidial production was observed.

Mycelium

The mycelium of the leaf smut fungus is especially distinguished by the formation of short side branches or knobs (fig. 55, C–E, and Plate XVII, 1). The hyphæ are most frequently from 2 to 3 μ in diameter, but may vary from 1.5 to 5 μ. The length of the cells varies from 4 to 30 μ. The mycelium is usually intercellular, in which case it sends out side branches which may penetrate the cells as haustoria or may merely apply themselves closely to the walls of the host cells (fig. 55, C). In many cases, however, the mycelium is intracellular (fig. 55, D, E, and Plate XVII, 1). A single mycelial thread growing through a cell and applied directly to the nucleus is shown in figure 55, D.

The mycelium invades all parts of stem, leaves, and rhizomes, occasionally even penetrating the inner wall of the epidermal cells. In badly diseased plants the tissues are found very thoroly infested with the mycelium, in which case it may even grow into the vascular bundles (fig. 55, E, and Plate XVII, 2). With renewed growth of the plants in spring the mycelium follows the growing tip of the shoots, passing into the leaves as these are developed. In the leaves it is usually found growing alongside and parallel to the vascular bundles, or it may be found in the bundle itself.

Fig. 56. MYCELIUM AND SPORE FORMATION OF USTILAGO STRIAEFORMIS

Drawings made from sections of stems or leaves of *Dactylis glomerata*

A–I, Mycelium in various stages. Binucleate stages are shown in B–E, H, and I. Four-nucleate stages are shown in A, F, and G. In G, H, and I the mycelium is shown with a gelatinous wall, the beginning of spore formation. The cell shown at the left in H, which was at the edge of a sorus, had not yet begun to gelatinize. × 1670

J–M, Short segments of the spore-forming threads, mostly binucleate. In most cases only the nucleolus can be made out with certainty at this stage. A gelatinous sheath was observed in only one case. × 1670

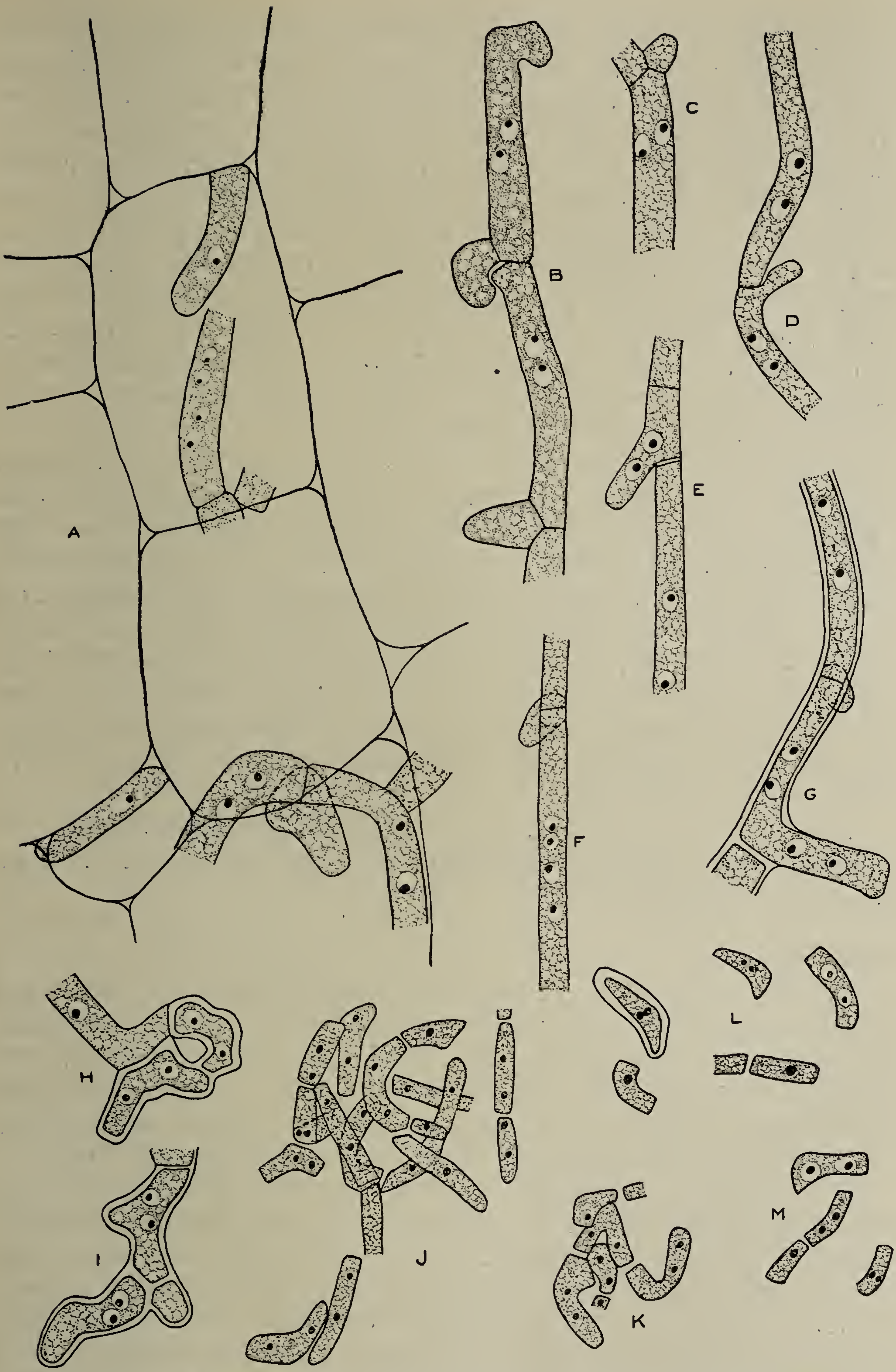

FIG. 56. MYCELIUM AND SPORE FORMATION OF USTILAGO STRIAEFORMIS

Considerable difficulty was experienced in staining nuclei and septa in the same mycelium. However, so far as observed, the cells of the vegetative mycelium are always binucleate (fig. 56, A–E, H, I). Division of the nuclei was not observed, but in a few cases a four-nucleate stage was found (fig. 56, A, F, G). This had apparently resulted from a more or less simultaneous division of the two nuclei, the septum not yet having been laid down. The nuclei are occasionally found side by side, but are usually at some distance apart in the cell. The point of origin of the binucleate condition was not determined, but in the case of the promycelia with clamp connections shown in figure 54, V and W, it is probable that the binucleate condition arose at this point. Whether this formation of septa and fusion of adjacent cells is a common occurrence before infection, the writer has no means of knowing at present.

Many of the vegetative cells have clamp connections at the septa (fig. 56, B, C, F). These are formed as an outgrowth of one of the cells, apparently the terminal cell. A wall is laid down between this outgrowth and the parent cell. Whether the wall between this connection and the other hyphal cell is dissolved was not determined with certainty; but if it is, another wall is quickly laid down so that the clamp is cut off from both cells. So far as observed, the nuclei did not pass through this clamp. It has been suggested by Kniep[9] that the clamp connection may serve for facilitating food transfer by exposing a larger surface for osmosis. If that is the case here, it is difficult to see why a wall should be laid down between it and both cells.

Branching of the vegetative mycelium occurs at the septa (fig. 56, E, G). Such a branch, containing two nuclei with the septum not yet laid down, is shown in figure 56, G.

Spore formation

The only account in literature of the mycelium and spore formation of the leaf smut fungus is by Fischer von Waldheim (1869-70), who studied the fungus on *Holcus mollis*. He states that the spores are formed on the ends of threads, like those of *Tilletia Caries*, but, on the other hand, the threads are larger in circumference and a gelatinous membrane surrounds the spore until maturity, as in the typical species of Ustilago.

Spore formation may occur in any region of the plant above ground. It usually originates in the parenchyma tissues of the leaf or in the cortical tissues of the stem outside the ring of sclerenchyma fibers. The mycelium that is to give rise to spore-forming threads begins to branch profusely in the tissues, producing a tangled mat of threads. This mycelium may remain intercellular for some time, forcing apart and crushing the cell walls by its continued growth and branching. Eventually, however, it penetrates the cell and here continues its growth, branching profusely and absorbing the cell contents, the nucleus being the last thing to disappear. A change now appears in the mycelium. The wall begins to gelatinize and the lumen becomes narrower and more deeply staining (fig. 56, H, I). Meanwhile the mycelium breaks up into short cells, usually not over from five to twelve microns in length. The cells may be branched, resulting in a Y-shaped appearance; or, as frequently happens, they may be U-shaped, due to a bending-back of the mycelium. In most cases these threads are densely intertwined and it is difficult to follow them for any distance (fig. 56, J, K). In rare cases, however, they grow out from the main sorus as septate, parallel strands (fig. 57, A). As the lumen grows narrower, it becomes increasingly difficult to stain the nuclei. In most cases only the nucleolus can be made out with certainty. As shown in figure 56, J-M, two nuclei are still usually present. Whether some cells are originally cut off with only one nucleus could not be made out with certainty. Meanwhile the gelatinous sheaths of the adjacent cells have become pressed together and apparently fused, so that it is impossible to distinguish them. Here and there individual cells soon begin to enlarge. It is during or just before this enlargement that nuclear fusion usually takes place. Only occasionally is a cell that has enlarged sufficiently to show the nuclei found to have more than one nucleus. Two such immature spores, with two nuclei side by side, are shown in figure 53, A. In another spore of figure 53, A, is shown a slightly later stage, in which the nucleus contains two nucleoli.

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[9] Kniep, Hans. Zeitsch. Bot. 5:619. 1913.

The spore-forming threads are crowded so closely together in the young condition that it would be manifestly impossible for all the cells to produce mature spores without an enormous increase in the size of the sorus. Consequently it appears that many of the cells disintegrate (fig. 57, I, M, R, S). Whether some or all of these cells had only one nucleus at the beginning of spore formation it is impossible to say. In the main body of the sorus the spore-forming threads and the young spores are so closely packed and interwined that their development cannot be followed accurately. In order to make out any details it is necessary to examine the isolated spores or threads around the border of the sorus. Here it is seen that the spores at the ends of the threads or the side branches are the first to be formed (fig. 57, G-J, O). Only very rarely is the maturest cell not at the end of the thread (fig. 57, F). However, a careful examination under favorable conditions shows that the cells farther back on the threads may eventually form spores also (fig. 57, E-H, K, N, O, R-T). In most cases this relation is very difficult to make out, due to the fact that the first-formed spore usually rounds up and loses all apparent

FIG. 57. SPORE FORMATION OF USTILAGO STRIAEFORMIS

Drawings made from sections of stems or leaves of *Dactylis glomerata*. All × 1670

A, Segments of spore-forming threads, with two immature spores

B–D, Immature spores, showing pointed ends

E, Two immature spores attached end to end

F, Three spores in a row, with the maturest one in the middle. Small, disintegrating masses of protoplasm are shown between the spores. The gelatinous sheath is only partly visible

G, H, Terminal and intercalary spore formation, showing also a well-developed gelatinous sheath

I, J, Terminal spore formation

K–T, Terminal and intercalary spore formation. A spore is shown on a side branch in O. The production of spines is shown in R–T

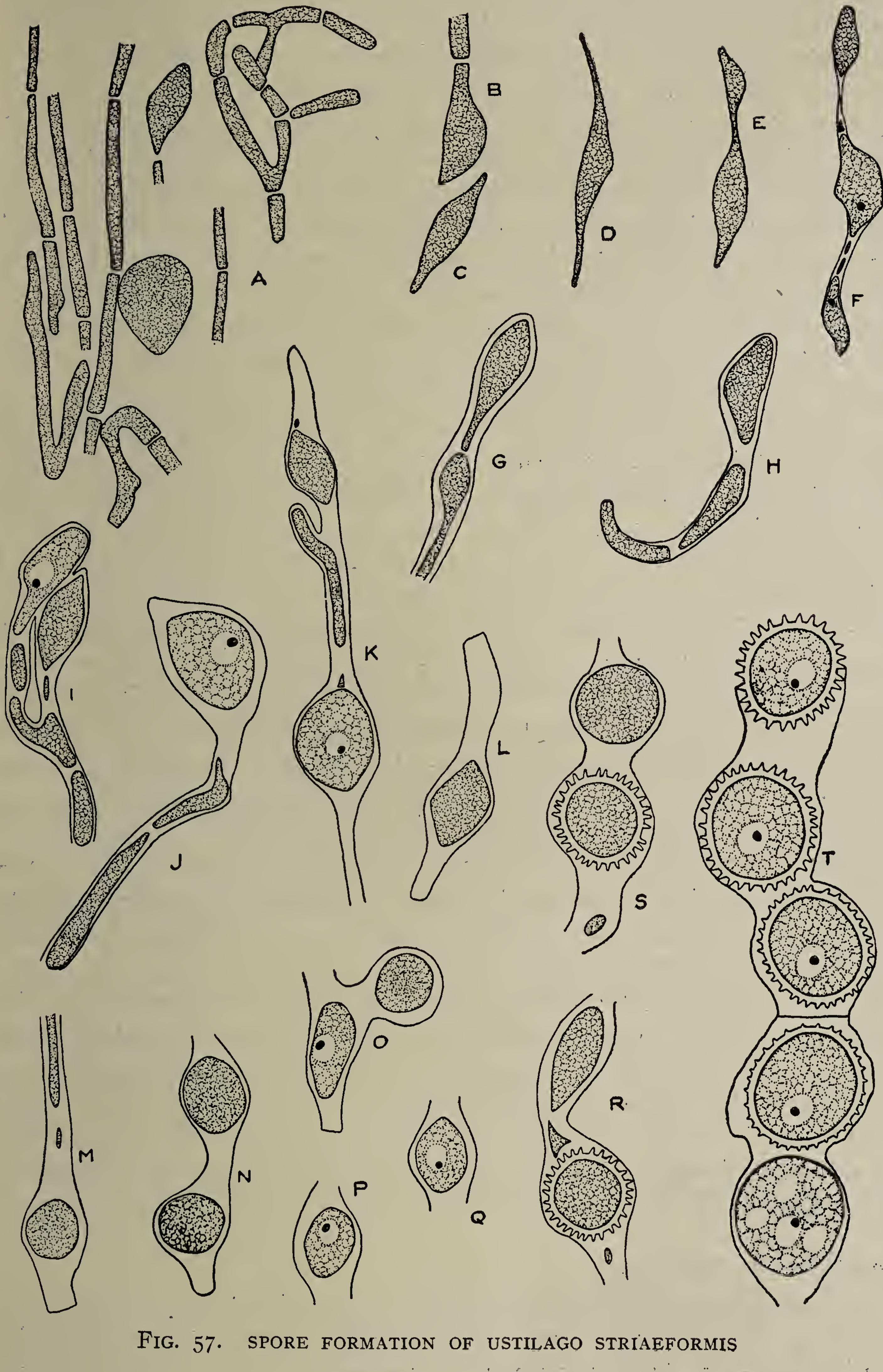

FIG. 57. SPORE FORMATION OF USTILAGO STRIAEFORMIS

connection with the other cells in the thread back of it. It is probably due to this fact that Fischer von Waldheim (1869-70:85) states: "Einerseits bildet sie [*Tilletia de Baryana*] ihre Sporen an den Enden der Fäden, wie *Till. Caries* und *endophylla.*" This intercalary formation of the spores in the spore-forming threads adds weight to the contention that the organism is a species of Ustilago rather than of Tilletia. In only one instance has the writer established the connection of more than two spores in a thread (fig. 57, T). In that instance the spores were formed in a thread which had extended considerably beyond the end of the sorus and had plenty of room and nutritive material in which to develop. The spores are seen to be older and to have larger spines at the upper end, while they become progressively younger toward the bottom, which was the point of connection with other threads.

If stained under favorable conditions, the young spore is found always to have a gelatinous sheath surrounding it (fig. 57, G-T). In its early stages the spore is usually more or less pointed at one or both ends (fig. 53, A, B, and fig. 57, B-I). In some cases these ends are blunt, in others they are long and sharp. As the spore enlarges the ends become rounded and the gelatinous sheath is pushed out. There is no visible wall about the spore, other than that formed by the gelatinous sheath, until it is nearly two-thirds grown. About this time, however, the spore becomes set off from its sheath by a thin wall, on the outside of which appear small granules which are the beginnings of the spines (fig. 53, C). As the spore matures the wall becomes darker and the spines become longer and thicker. The growth of the spines appears to be due partly to drying and shrinking of the material in the interstices, and partly to outward growth of the spines themselves. The relation of the spines to the spore wall is most clearly shown by plasmolyzing the contents slightly. By the time the spores are mature, the gelatinous sheath has entirely disappeared (fig. 53, D, E).

In the young sorus the first spores are formed in the center. As the sorus becomes older, spore formation gradually proceeds outward (Plate XVII, 3). In some cases the mycelium spreads no farther than the limits it occupied when spore formation began; but in the majority of cases it continues to invade new cells, branching and giving rise to additional spore-forming threads. It is due to this continued progress of the mycelium that fusion of adjacent sori occurs.

Inoculation and infection

No inoculation experiments with this fungus have been reported in literature. Clinton (1900) says that infection probably occurs thru the germinating seed, but he cites no experimental work. From experiments of the writer it appears that inoculation and infection occur at blossoming time. The spores are carried to the opening flowers either by wind or by insects. Here they germinate, sending out a germ tube which penetrates into the ovary and remains in the young embryo in a more or less dormant condition until it begins growth after planting.

Seed inoculation.—On November 4, 1913, timothy seed bought of a local dealer was inoculated with spores of *Ustilago striaeformis* taken from timothy plants that had been kept in the laboratory for three months. Part of this treated seed was sown in the greenhouse along with clean seed. The remaining treated seed was sown in a box, and after germination had started the box was kept in a rather cool room until the plants were between two and three inches high. These plants were then placed in the greenhouse. The disease made its first appearance on the leaves of a number of the plants about four months later, and on April 1, 1914, the results shown in table 1 were obtained:

TABLE 1. RESULTS OF TIMOTHY SEED INOCULATIONS MADE ON NOVEMBER 4, 1913

	Percentage of smutted plants	
	Inoculated	Check
Plants kept in greenhouse	2.0	2.5
Plants first kept in cool room	1.9	1.8

After April 1 only one additional plant became diseased. Some of these plants later became so badly diseased that they died, while a few of the others produced seed on one or more shoots of the stool.

On April 18, 1914, a series of inoculations were made on thirty-two species of grasses, using a mixture of fresh spores from timothy, spores that had been kept outside over winter, and spores that had been kept in the laboratory for several months. The seed was inoculated by mixing it with smut spores in water. Timothy seeds from five different sources were used, redtop seeds from three sources, and Kentucky bluegrass seeds from three sources. On July 22, when these plantlets were examined, those of the timothy from two sources showed a small percentage of smutted plants in the case of both treated and untreated seeds (table 2). All the other plants remained healthy.

TABLE 2. RESULTS OF TIMOTHY SEED INOCULATIONS MADE ON APRIL 18, 1914

	Lot 1		Lot 2	
	Number of stools	Percentage smutted	Number of stools	Percentage smutted
Treated	146	2.0	291	1.0
Check	206	1.9	217	1.4

On May 11, 1914, a series of inoculations similar to those described above were made, using eight species of grasses, including seeds from two sources each of redtop, Kentucky bluegrass, and timothy. When the plantlets were examined on July 22, timothy plants from one source (lot 1 of table 2) showed a small percentage of diseased plants in the case of both treated and untreated seeds (table 3). When examined again on August 17 the number of diseased plants in this lot had increased slightly, but all the other plants were healthy.

TABLE 3. RESULTS OF TIMOTHY SEED INOCULATIONS MADE ON MAY 11, 1914

	Number of stools	Percentage of smutted plants	
		July 22	August 17
Treated	197	2.5	2.5
Check	144	2.1	2.8

As shown in the tables, the number of smutted plants in these experiments was in no way affected by inoculating the seed. The experiments are inconclusive, however, since the spores failed to germinate in contemporaneous germination tests.

Blossom inoculation.— Blossoms of redtop, orchard grass, timothy, and Kentucky bluegrass were inoculated with spores taken from each of the hosts. The inoculations were made in most cases either by dusting the spores on the stigma or by spraying them on in water with an atomizer. Unfortunately the plants used in this experiment were later accidentally cut down, thus destroying the experiment.

Later in the summer these inoculations were repeated on second-growth timothy blossoms, using spores from timothy and redtop. A number of the resulting seeds were placed to germinate between moist filter papers, and as soon as growth started sufficiently to show that the seeds were not killed they were fixed and infiltrated with paraffin, and sectioned. In one case typical smut mycelium was found in the seed, thus showing that infection had occurred. The remaining seed was sown in the greenhouse and later transplanted to the field, or was sown directly in the field, but owing to the extremely wet season the plants were completely smothered by weeds during the writer's absence. The writer expects to repeat these experiments on a more extensive scale.

In the summer of 1914 a quantity of viable timothy seed was collected from diseased plants. Some of this seed was germinated between moist filter paper, and as soon as sufficient growth had started to be sure that the seeds had not been killed by the fungus they were infiltrated with paraffin and sectioned. In a few of these mycelium was found (fig. 58). It was not possible, however, to tell whether this mycelium had come from blossom infection or had grown into the seed through the funiculus from the diseased rhachilla. The remaining seed from these plants was sown in the field, but suffered the same fate as that from the blossom inoculation experiment mentioned above.

Soil inoculation.—In order to test the possibility that the spores might live in the soil for some time, the following experiment was performed: On April 14, 1914, plots 2, 3, 4, and 5 (fig. 59) were inoculated with fresh spores from timothy. On the same day timothy seed procured from a local dealer was sown in plots 1 and 5, and seed treated by covering it with spores was sown in plot 6. After one week seed was sown in plots 4 and 7, after three weeks in plot 2, and after six weeks in plot 3. No diseased plants were produced in any of the plots. This experiment is inconclusive, since no germination of spores was obtained in contemporaneous germination tests.

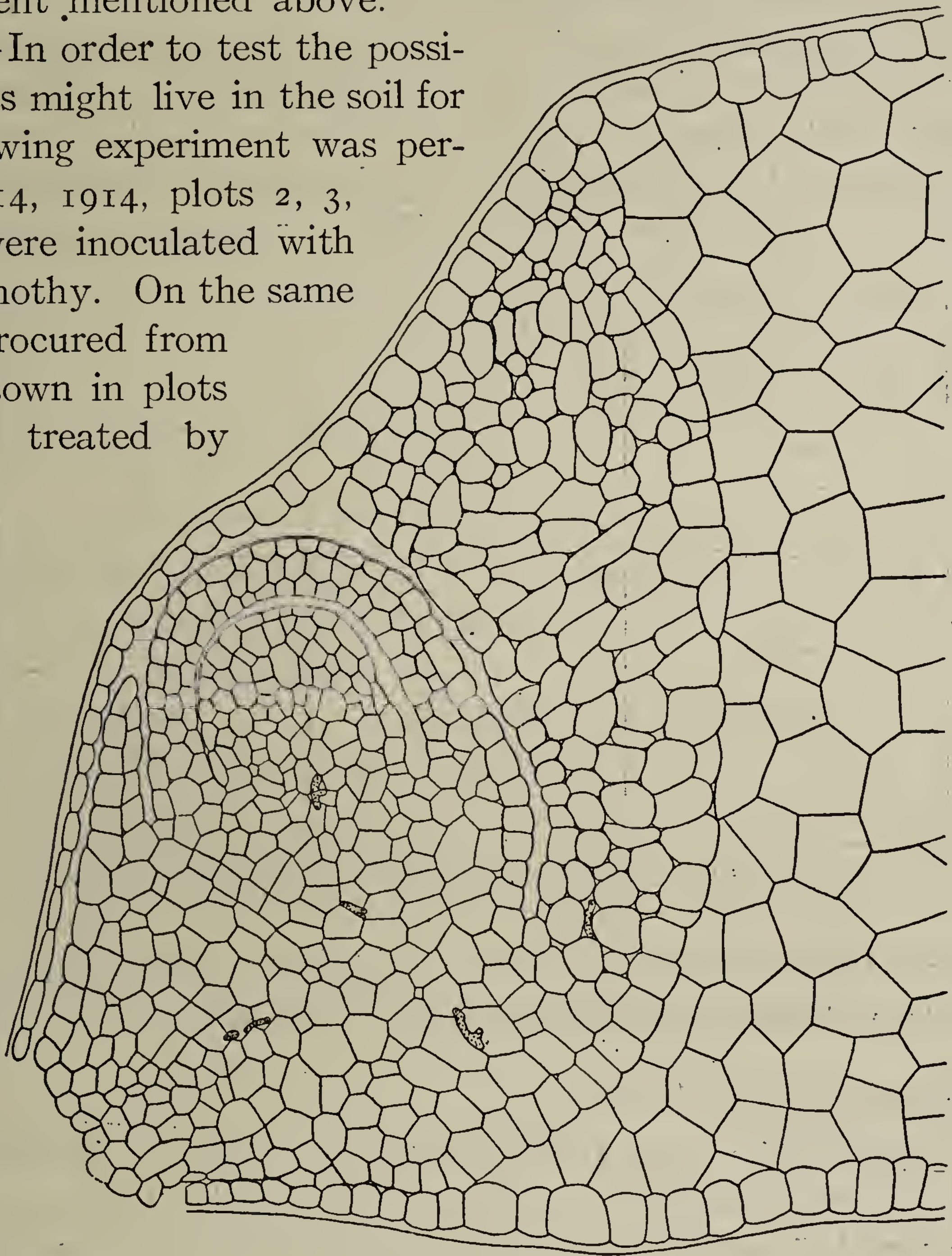

FIG. 58. SECTION THROUGH A TIMOTHY SEED, SHOWING MYCELIUM IN THE EMBRYO. X 175

Inoculation of growing tissues.— On March 1, 1914, eight timothy plants were inoculated with both fresh and old spores taken from diseased timothy. In some cases the spores were placed on the uninjured growing tissues at the top, while in others the tissues were injured by needle pricks or by cutting with a scalpel. In some of the stools a number of the stalks were cut off and the young sprouts that started out were covered with spores. In all cases the plants were kept moist by covering them with a bell glass. No infection was obtained on any of the plants.

Later in the summer these experiments were twice repeated on timothy and redtop, using spores from timothy, redtop, and bluegrass. The spores from redtop showed from five to twelve per cent germination on slides in petri dishes. In no case did any infection result.

Examination of inoculated seedlings.—Timothy and redtop seeds were inoculated with spores from timothy and redtop, respectively, and placed in a moist chamber between moist filter papers. The spores from redtop showed about ten per cent germination. Two days later additional spores were dusted on the seeds, and in this case the spores from redtop showed four per cent germination. The germinated seedlings were removed from time to time and were fixed and sectioned in paraffin, but in no case was any mycelium found in the tissues.

<table>
<tr><td>1
Check</td><td>2
3 weeks</td><td>3
6 weeks</td><td rowspan="2">7
Check</td></tr>
<tr><td>4
1 week</td><td>5
Seed sown at once</td><td>6
Seed inoculated</td></tr>
</table>

FIG. 59. CHART SHOWING PLAN OF SOIL INOCULATION EXPERIMENT

Summary of life history

The fungus may pass the winter in three different ways: first, as mycelium and spores in the green tissues of the plants; second, as mycelium in the dormant embryo of the seed; and third, as mycelium in bulbs and rootstocks of perennial plants. In the first method the fungus persists in the green tissues, usually spreading very little if at all until renewed growth starts in the spring. However, over the steam pipes on the Cornell University campus, where the grass maintains a slight growth during the winter, the writer has found the fungus active thru the entire winter. In the second case, when the seed is sown the mycelium becomes active, growing up with the young plant and spreading out into the leaves, where, after a period varying from two and one-half to six months or more, it first makes itself evident by the elongate sori. In the third case, when the plants start growth in the spring the mycelium grows out into or with the new shoots, producing the lead-colored sori very soon after growth starts. Additional sori are produced all summer whenever there is any new growth of the diseased plants. In those plants that produce underground stems the mycelium grows thru these, keeping pace with the growing tip and establishing itself in the newly formed plants. The writer has found plants of Kentucky bluegrass and a creeping variety of *Agrostis alba* affected in this manner at a distance of over four feet from the parent plant. At blossoming time the spores are distributed to the stigmas of the opening flowers, where they germinate, giving rise to a germ tube which penetrates into the ovary, in this way infecting the seed. When a plant is once infected, it apparently never becomes free from the fungus. The writer has observed the disease in the same plant for three successive seasons. The old dead leaves, showing sori formed the previous summer, may be found in the spring surrounding the new shoots, which soon show the disease.

PATHOLOGICAL HISTOLOGY

The only mention in literature of the effects of this fungus on the tissues is by Strohmeyer (1896). He gives a brief account of the alterations caused on a number of different plants.

An examination of diseased leaves shows that the sori originate in the mesophyll between the vascular bundles (Plate XVII, 5 and 6). They may originate either near the upper or the lower epidermis, or midway between them. The mesophyll cells surrounding the young sorus are frequently found to have increased in diameter and to have lost their chlorophyll content. The cell walls persist for some time after the contents of the cells have been absorbed, and may be found extending into the young sorus as isolated strands. Eventually, however, they disappear. If the sorus originates near the surface of the leaf, the epidermal cells are early found to have increased in diameter, especially tangentially, apparently even before any particular pressure is exerted on them by the enlarging sorus, since they may be hypertrophied for a considerable distance above or below the sorus. As the sorus increases in size, additional mesophyll cells are invaded and are broken down partly by pressure and partly by dissolution of the walls. At the same time the epidermis is pushed out due to this pressure, the cells increasing greatly in tangential diameter and becoming somewhat flattened (Plate XVII, 6).

In the case of large sori the vascular bundles on either side are forced to one side and the nourishing cells surrounding them are crushed. In most cases the xylem and the phloem elements appear to be very little affected. The walls of the sclerenchyma fibers accompanying the larger bundles are frequently less lignified than those above or below the sorus. Adjacent sori occasionally may fuse laterally, in which case the bundle between them is pushed toward one epidermis, usually the upper, while the opposite epidermis is pushed out. When a large sorus is formed adjacent to a small vascular bundle consisting of only three or four cells, the bundle may be completely obliterated at that point but will still be found above and below the spore mass. Cross-connections of the bundles may be either pushed aside or completely destroyed.

The spore-forming mycelium continues to spread until it reaches one or both of the epidermal layers. The uninjured epidermal cells are very seldom invaded by the mycelium. As the sorus becomes larger the epidermal cells may be crushed and ruptured by the pressure from within, or, as frequently occurs, the inner wall of the epidermal cells is dissolved by the fungus, the spores then pressing against the outer wall. This is later ruptured either by pressure or by the solvent action of the fungus. The writer has found both the lower and the upper epidermis to be ruptured in diseased leaves kept undisturbed under a bell glass. In this case the rupture of the second epidermis could have occurred only by the wall being dissolved until it became exceedingly weak.

In the stem the sori are usually found in the cortex just beneath the epidermis and outside the ring of sclerenchyma fibers (Plate XVII, 4). The cortical cells are broken down and the epidermal cells are enlarged in their tangential diameter and pushed out. The epidermal cells are eventually ruptured just as they are in the leaves.

EFFECT OF ENVIRONMENTAL FACTORS

Ule (1884:216) reports that protected places, especially where protected in winter by snow as on the west side of hills, are favorite places for this and related fungi. He rarely, if ever, found the disease on open meadows. Griffiths (1903) states that in California the disease seems to be confined to well-drained areas abundantly supplied with seepage from ditches, rather than to poorly drained or drier parts of meadows.

In New York the writer has not observed any difference in the amount of this disease between wet and dry soils or exposed and protected places, provided the grass was pastured or otherwise kept to the same size in both locations. However, especially in the case of Kentucky bluegrass, if the plants are allowed to reach maturity there is usually much less smut in the rich, moist soils. This is apparently due to the fact that in the rich soils the healthy plants grow so rank and tall that they are able to crowd out the diseased, stunted plants. This probably accounts for the fact that few diseased Kentucky bluegrass plants can be found along moist roadsides, while they are extremely common on lawns where the grass is mowed.

CONTROL

No experiments are recorded in literature on the control of leaf smut, but Pammel (1890) and Clinton (1900) have suggested the possibility of controlling the disease by seed treatment.

Since, as already shown, infection occurs thru the blossoms, it follows that if the grower plants seed free from the smut fungus, the grass will be entirely free from the disease. This method, however, is not feasible under most conditions, since the disease is so universally present. Further, many growers buy their seed from dealers and thus have no means of knowing where the seed came from or what percentage of it may be infected. In such a case the only remedy lies in treating the seed.

EFFECT OF SEED TREATMENT ON GERMINATION

Before any experiments were undertaken on the control of this disease by seed treatment, a number of germination tests with timothy seed were performed in order to determine the point of injury to the seed by the various treatments. The seeds were treated and then germinated between

TABLE 4. EFFECT ON GERMINATION OF TIMOTHY SEED, OF TREATMENT WITH FORMALDEHYDE AND COPPER SULFATE SOLUTIONS

Treatment	Percentage of germination	
	Lot 1	Lot 2
Control, soaked in water 1 minute	97	60
Control, soaked in water 1 hour	95	64
Control, soaked in water 2 hours	92	....
Control, soaked in water 10 hours	92	64
Formaldehyde solution, 40 per cent, 1 pint to 38 gallons of water		
½ hour	95	....
1 hour	94	....
2 hours	94	....
4 hours	91	....
10 hours	90	....
24 hours	85	....
Formaldehyde solution, 40 per cent, 1 pint to 76 gallons of water		
½ hour	94	53
1 hour	92	55
2 hours	93	51
4 hours	90	51
10 hours	86	51
24 hours	82	50
Copper sulfate solution, 2 per cent		
1 minute	92	54
2 minutes	88	56
5 minutes	90	54
10 minutes	91	50

moist filter papers in petri dishes. The experiments were run in triplicate in each case, two hundred seeds being placed in each petri dish. The seeds in one petri dish were placed to germinate at once, while those in the other two dishes were first kept dry for forty-eight hours. It was found that in all treatments, including the checks, better germination occurred where the seed was placed to germinate at once after treating than where it was dried for two days. This increase amounted to from one to seven per cent. The averages for all three petri dishes are given in tables 4 and 5. The germination of seed after treatment with various formaldehyde and copper sulfate solutions is shown in table 4. From these results it is apparent that timothy seed may be treated with one pint of forty-per-cent formaldehyde solution to thirty-eight gallons of water for from two to four, or even ten hours, or with two-per-cent copper sulfate solution for ten minutes, without materially affecting its germinating power. The results of treating timothy seed with hot water are given in table 5. Before the seed was plunged into hot water it was held for one minute in water at a temperature four or five degrees below that at which it was to be treated. The temperature of the water did not vary over 0.25 degree above or below the stated temperature, and in most cases not over 0.15 degree. Judging from the results given in table 5, favorable treatments would appear to be with water at 54° C. for ten minutes or 52° C. for fifteen minutes, with a previous soaking in cold water of from six to eight hours.

TABLE 5. EFFECT ON GERMINATION OF TIMOTHY SEED, OF VARIOUS TREATMENTS WITH HOT WATER

Time soaked in cold water (hours)	Time held in hot water (minutes)	Temperature of hot water (centigrade)	Percentage of germination	
			Lot 1	Lot 2
4	Control	....	92	....
6	Control	....	94	60
10	Control	....	95	....
4	5	50°	97	....
4	10	50°	96	....
4	15	50°	96	....
4	20	50°	95	....
4	25	50°	95	....
6	5	50°	95	....
6	10	50°	95	....
6	15	50°	95	....
6	20	50°	93	....
6	25	50°	92	....
10	5	50°	94	....
10	10	50°	90	....
10	15	50°	93	....
10	20	50°	94	....
10	25	50°	89	....

TABLE 5 (*concluded*)

Time soaked in cold water (hours)	Time held in hot water (minutes)	Temperature of hot water (centigrade)	Percentage of germination	
			Lot 1	Lot 2
4	5	52°	95	....
4	10	52°	92	....
4	15	52°	93	....
4	20	52°	92	....
4	25	52°	92	....
6	5	52°	97	57
6	10	52°	95	45
6	15	52°	94	43
6	20	52°	91	33
6	25	52°	89	29
10	5	52°	95	....
10	10	52°	95	....
10	15	52°	91	....
10	20	52°	89	....
10	25	52°	88	....
4	5	54°	93	....
4	10	54°	93	....
4	15	54°	89	....
4	20	54°	89	....
4	25	54°	88	....
6	5	54°	94	47
6	10	54°	92	44
6	15	54°	85	38
6	20	54°	85	27
6	25	54°	83	21
10	5	54°	93	....
10	10	54°	88	....
10	15	54°	85	....
10	20	54°	86	....
10	25	54°	79	....

EFFECT OF SEED TREATMENT ON PERCENTAGE OF SMUT

During the summer of 1914 a number of experiments were conducted on the control of leaf smut by seed treatment. In one experiment the seeds, except those in a part of the check, were dusted with a mixture of spores taken from fresh plants and from dried plants kept over winter in the laboratory or exposed outdoors over winter. The results are given in table 6. As shown in the table, the dusting of spores on the seed had no effect on the amount of smut produced. However, the seed was already infected, as shown by the checks, so that data on seed treatment were obtained. The hot water treatments gave perfect control in both cases. The plots treated with formaldehyde and copper sulfate solutions showed less smut than the checks, but, owing to the small number of plants used and the low percentage of smut, this may have been due

TABLE 6. RESULTS OF TREATING TIMOTHY SEED FOR SMUT

Treatment	Number of stools	Percentage of smut
Check, no treatment	396	2
Check, seed dusted with spores	444	2.25
Formaldehyde solution, 40 per cent, 1 pint to 45 gallons of water for two hours	416	1.5
Copper sulfate solution, 2 per cent, for two minutes	406	1
Cold water for six hours, hot water at 52° C. for fifteen minutes	510	0
Cold water for six hours, hot water at 54° C. for ten minutes	322	0

to experimental error. The timothy seed was the same as lot 1 in table 2. In the other experiments no smut occurred even in the check plots. Further experiments during the summer of 1915 were nullified by wet weather.

These results, while not conclusive, point strongly to the probability of controlling this disease by treating the seed with hot water.

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SUN-SCALD OF FRUIT TREES
A TYPE OF WINTER INJURY

A. J. MIX

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SUN-SCALD OF FRUIT TREES: A TYPE OF WINTER INJURY[1]

A. J. Mix[2]

The type of winter injury to fruit trees to be discussed in this paper is the well-known injury to the southwest, or sun-exposed, side of the trunk, commonly known as sun-scald. It is usually made evident in late spring by the death of patches of bark, which often peel off and expose the sapwood, but in some cases adhere firmly to the wood, forming sunken, canker-like areas. Such dead-bark areas are often inhabited by higher fungi — wound parasites or saprophytes. One of the commonest forms following sun-scald in New York is *Physalospora Cydoniae* Arnaud. Similar injured areas are often found on the upper, sun-exposed sides of large branches. Probably these injuries are caused in the same manner as those on the trunk.

Sun-scald is so named because it is believed to be brought about by some interaction of sun and cold on the sunny side of the trunk in late winter.[3]

Two other types of injury that are somewhat closely related to sun-scald are crotch injury, occurring at the head and in the crotches of rapidly growing branches, and crown injury, or crown rot, occurring at the crown, or base, of the trunk. For the purposes of this paper the following distinction is made: Injury localized on the southwest side of the trunk, whether at the crown, at the head, or on the intermediate part, is considered typical sun-scald. Injury typically occurring at the head and in the crotches, or at the crown, without relation to the points of the compass in either case, is designated as crotch injury or crown rot, respectively. All three types of injury are herein discussed.

OBSERVATIONS ON SUN-SCALD INJURY

In the northern half of the Champlain Valley, New York, including parts of Essex and Clinton Counties, is an area lying between Lake Champlain and the Adirondack Mountains, in which some attention is given to growing apples on a commercial scale. The varieties most grown

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[1] Also presented to the Faculty of the Graduate School of Cornell University, February, 1916, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

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[3] Possibly this injury would be more properly called winter sun-scald, to distinguish it from sun-scald or sun-scorch resulting from the direct action of the sun in midsummer. Considerable mention of summer sun-scald is made in literature. Hartig (1894) describes an interesting case of the injury to spruce.

are Fameuse, McIntosh, Ben Davis, Northern Spy, Rhode Island, and Wealthy. A few Baldwin orchards also are found.

The writer had occasion to spend much of his time in this locality during the summer seasons of 1913, 1914, and 1915. One of the conditions noted in the early part of the season of 1913 was the almost universal prevalence in these various orchards of trunk injury to the southwest side of the tree. This injury was not recent, but had apparently occurred one or two years earlier. The unanimous opinion of the growers was that it had occurred during the winter of 1910-11. This view was substantiated by sawing into several injured trunks and counting the number of annual rings formed since the injury.

In the summer of 1913 a careful survey was made of a number of orchards, in order to determine if possible the relation of certain factors to the amount of injury. The survey was never extended to include all the orchards in this region, and served merely to confirm conclusions that might be drawn from a somewhat casual observation. It is therefore not reproduced in any detail here, but the most evident facts gained from a study of it are stated.

There are a number of very old orchards in the lower Champlain Valley, but the majority of commercial orchards are from twenty to thirty years old. There are also many younger orchards. The injury was practically confined to orchards between the ages of eight and thirty years. None of this recent injury was observed in the very old orchards, tho evidences were found of one or more earlier injuries, the dates of which were not determined.

The injury was confined almost entirely to the southwest side of the tree. Trees leaning to the northeast were most severely injured. In one or two orchards, trees of the Ben Davis variety were found to have a number of injured places on any and all sides of the trunk.

The injury might occur at any height on the trunk, might extend from the crown to the head involving the whole of the southwest side of the trunk, or might appear at from one to several places at various heights. The commonest form, however, was an injured area beginning at a point from ten to twenty-five centimeters above the crown and extending to within a short distance below the head; in other words, the part of the trunk midway between the crown and the head was oftenest injured (Plate XVIII). Only a few cases were found in which the injury was confined to the region of the crown. A few cases of crotch injury were observed, one of the most striking being in a twenty-years-old Northern Spy orchard. The trees in this orchard were comparatively low-headed, and a large number of nearly upright main branches originated from almost the same point. In these trees the injury was chiefly in the crotches of these branches, usually extending up along the branches themselves for a distance of several centimeters. In this orchard the injury was localized on the southwest side of the tree.

The number of injured trees in the orchards examined averaged about twenty to twenty-five per cent of the total number of trees.

No satisfactory conclusions could be drawn as to the relation of soil type, location, exposure, or previous cultural treatment of the orchard, to the amount of injury. However, there are a few orchards on extremely light, infertile soils. The trees on these soils are normally less well-grown, less vigorous, and shorter-lived than the same varieties on heavier types of soil. They were found to be much more affected by sun-scald injury. It seems probable that this is an indirect soil relation, due to the influence of the soil on the vigor of the tree.

There seemed to be a fairly well-marked range of susceptibility of varieties. Ben Davis suffered the most, Northern Spy next, and Fameuse, McIntosh, Baldwin, and Rhode Island somewhat less. Not a sufficient number of Wealthy trees were examined to warrant a statement as to the relative susceptibility of that variety.

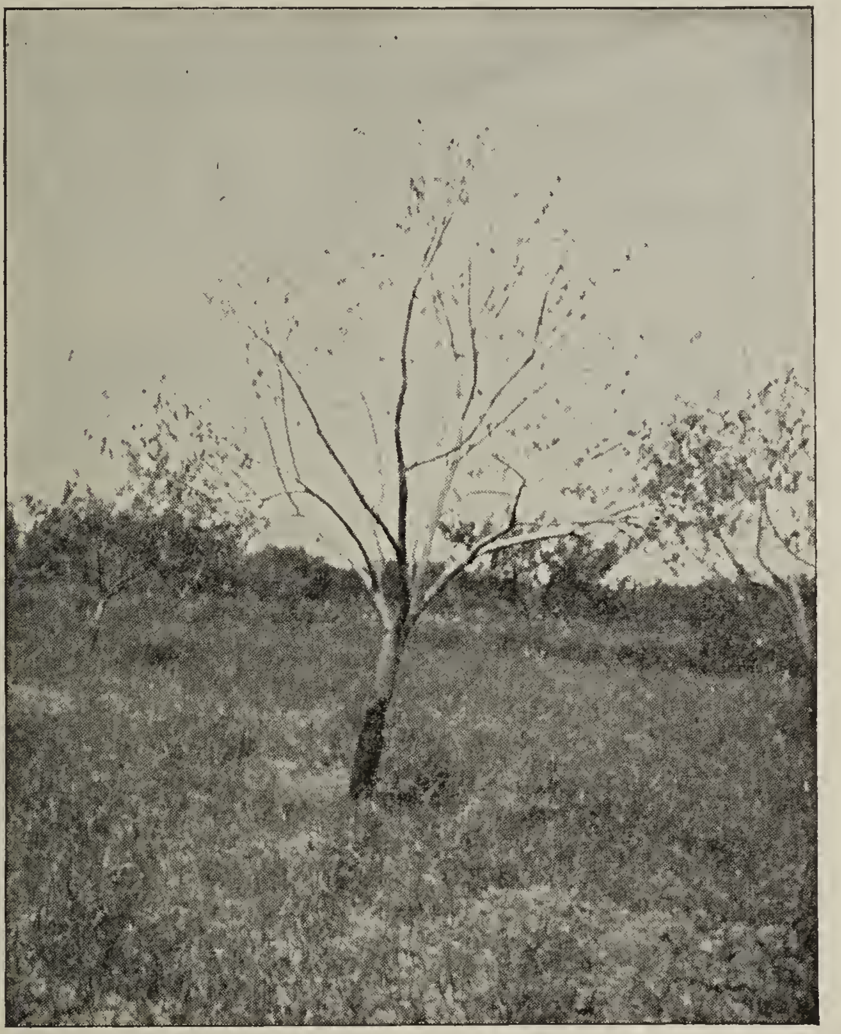


FIG. 60. BEN DAVIS APPLE TREE THE ROOTS OF WHICH WERE WINTERKILLED DURING THE WINTER OF 1913-14

Photograph made in June, 1914. This tree has also an old sun-scald injury which has been treated with gas tar

It is of interest in this connection that in the winter of 1913-14 there was in this locality a great amount of winter injury to roots of apple trees from one to twenty years of age, and in a few cases to much older trees. This injury was in many instances severe, a number of trees having their whole root system killed, and the injury often extended to the crown, killing the cambium and the outer sapwood so that the bark lifted away from the trunk around its whole circumference for a distance varying from two to six or eight inches above the soil. Fall plowing seemed to have increased the amount of this injury somewhat, and it was also more prevalent on light soils and wind-exposed locations. But the most striking fact observed was the marked susceptibility of the Ben Davis variety. The writer could find no Ben Davis orchard that had entirely escaped injury. In many of these from fifty to seventy-five per cent of the trees were in a dying condition, and if they survived the summer of 1914 they succumbed early in 1915. (Fig. 60.) Northern Spy and Wealthy trees also suffered severely, altho not to nearly so great a degree as Ben Davis. It appears that the Ben Davis variety is not a hardy tree in the lower Champlain Valley, and it may be questioned whether Northern Spy is.

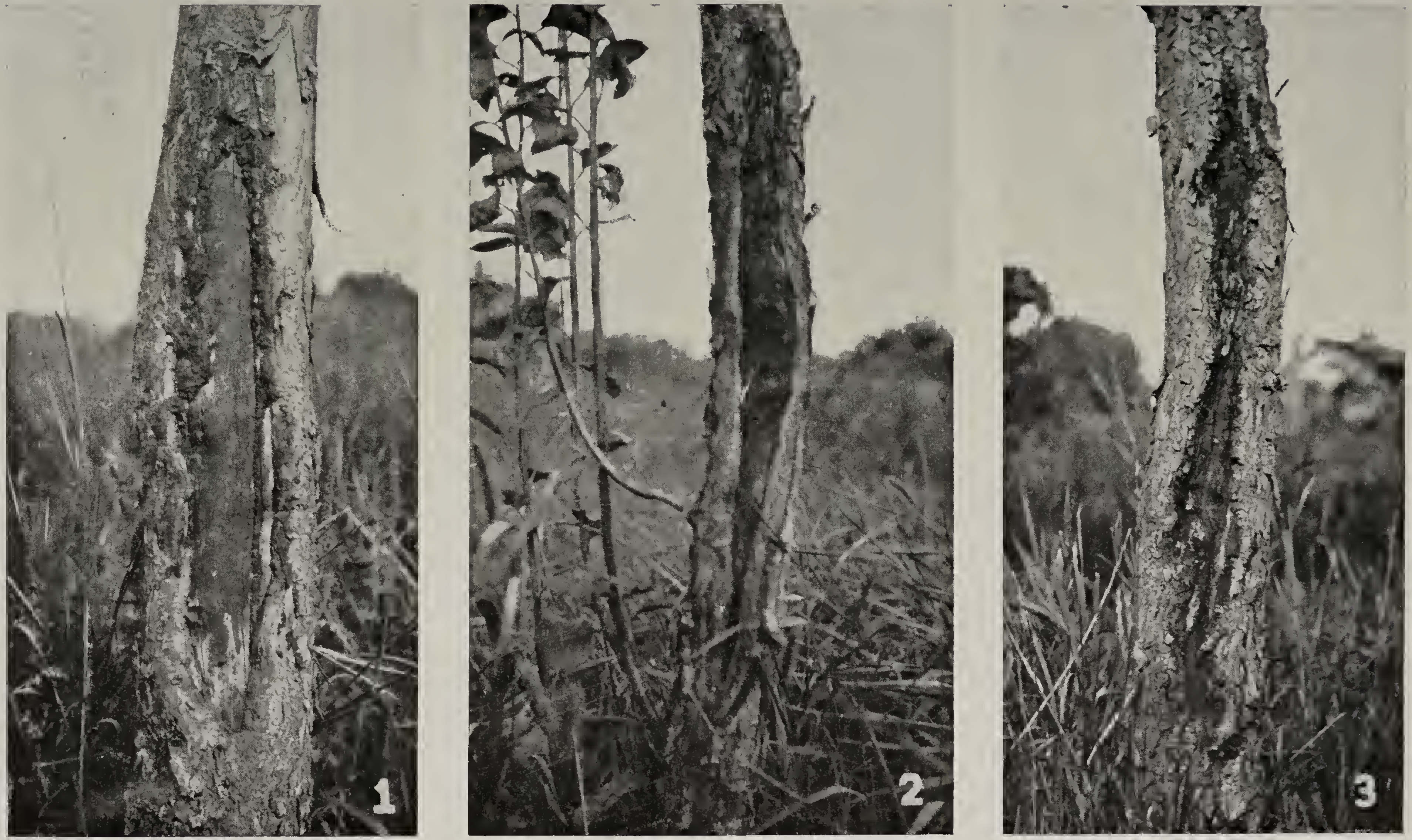
A point of horticultural interest worth mentioning in connection with this root injury is that, altho some of these Ben Davis trees were root-grafted trees, many of them, according to the owners' statement and the appearance of the trunk at the union, were originally budded trees and therefore not on their own roots. In this case the hardiness of the stock seems to have been influenced by the scion.

SUN-SCALD INJURY OCCURRING IN THE WINTER OF 1913-14

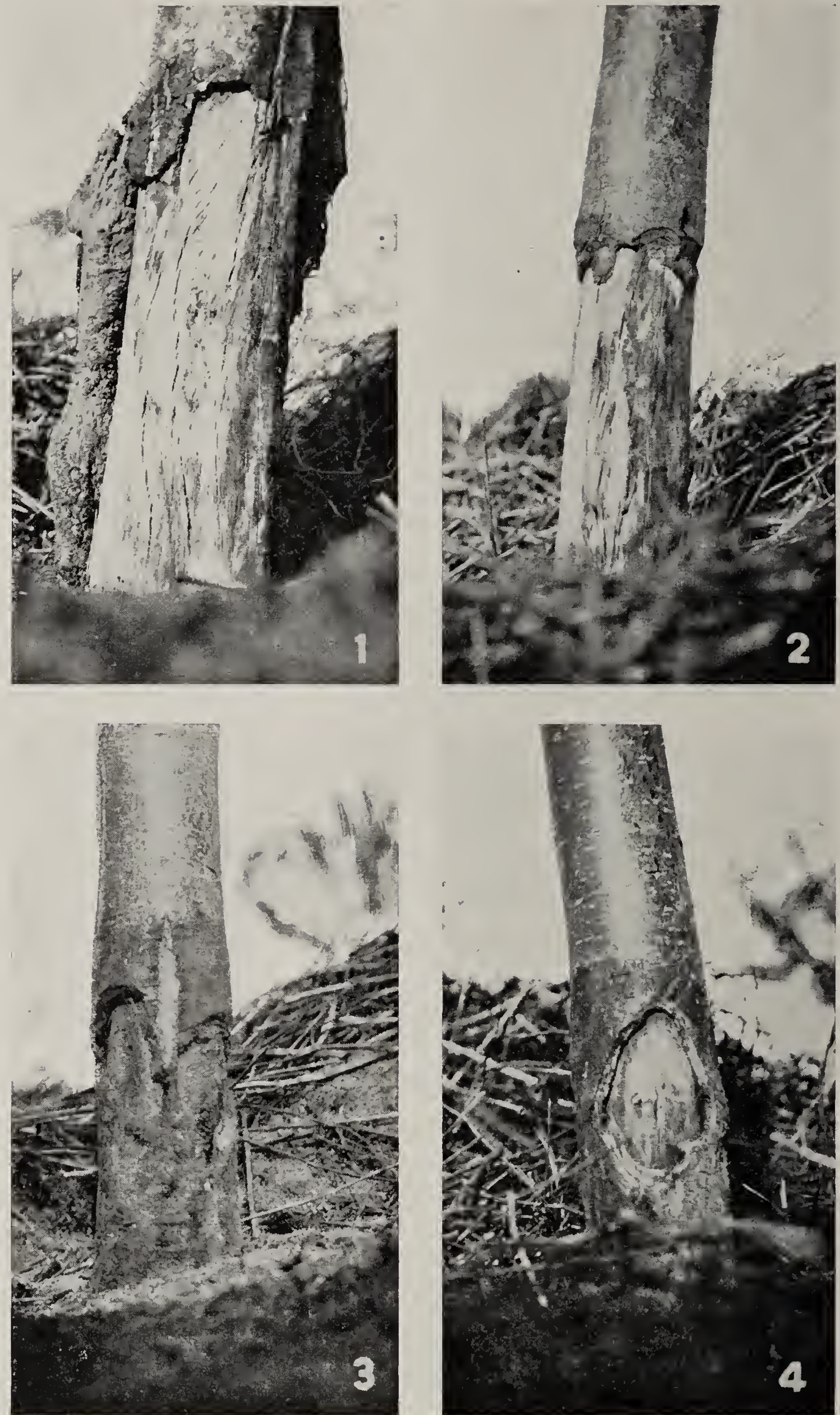
A very interesting case of sun-scald injury occurred in the orchard of W. E. Everett, at Peru, New York, during the winter of 1913-14. This is a small orchard of two hundred and sixty trees, seven years old at the time the injury occurred. The trees in the first, second, and fourth to eighth rows, or one hundred and sixty-three trees on the west side of the orchard, were mostly of the Wealthy variety; the trees in the third row, twenty-two trees, were of the Mann variety; the remaining three rows of trees, on the east side of the orchard, seventy-five trees, were Fameuse. The soil is light and gravelly, and not particularly fertile, but the trees had been well manured, cultivated, and sprayed, and were fairly well grown and vigorous. The soil was somewhat better in the western half of the orchard, and the trees there were slightly larger. The injury was much severer in this part of the orchard. It was thought that this indicated a less degree of hardiness of the Wealthy variety, but no definite conclusion could be drawn.

Late in the summer of 1913, the owner, in the hope of protecting his trees against the attack of borers, painted the trunks with gas tar for a distance of about one foot from the ground. Several rows of trees, two or three years younger and of an unknown variety, to the west of the Fameuse, were not so painted. The injury was confined entirely to the trees that were painted, and the injury to each was confined to the blackened part of the trunk.

The injury was first noted on April 30, 1914, and a brief examination of it was then made, followed by a more careful examination of every affected tree a short time later. The bark was found to be loosened from the wood, and the sapwood and the cambial area were discolored



OLD SUN-SCALD INJURIES OBSERVED IN THE LOWER CHAMPLAIN VALLEY IN THE SUMMER OF 1913
Photographs taken in August, 1915



SUN-SCALD INJURY TO TARRED TRUNKS OF APPLE IN WINTER OF 1913-14
Photographs taken in August, 1914, after the dead bark had been trimmed away

dark brown; but the bark itself was green and apparently alive. The injury could not have been due to the direct action of the gas tar on the tissue, since only the very outer bark showed any injurious effect from the tar, the inner bark being normal in color and appearance.

Of the two hundred and sixty trees in this orchard, one hundred and eleven were injured to some extent; on sixty-five of these the bark was loosened from the wood for one-third of the circumference or more; on eight of the latter the bark was loosened thruout the entire circumference or nearly so, in some cases a very narrow strip of uninjured wood and bark being found on the northeast side. Three trees had their bark loosened from the trunk all the way around.

In cases in which the bark was loosened thruout the whole circumference or nearly so, it was usually split open in one or more places. Most of these splits were on the southwest side of the trunk. In less severe cases the localization on this side was even more marked; where the bark was loosened for a space of from one-third to two-thirds of the circumference this loosened area was invariably on the southwest or the west side. In the case of the forty-six trees showing less severe injury, this injury consisted of small to large areas on the southwest side of the trunk, where the bark was lifted from the wood.

The above-mentioned facts point to the conclusion that the injury was of the sun-scald type and that the application of gas tar was the indirect cause of its occurrence. The black color probably caused the tissue of the bark to absorb more than the normal amount of heat, so that proper conditions for the occurrence of sun-scald were brought about. This unusual rise in temperature undoubtedly did not occur on unblackened trees. No cases of sun-scald on trees whose trunks were not treated with gas tar were found to have occurred in this region during the winter of 1913-14. Some observations are reported later in this paper on the temperatures that may occur in blackened trunks.

The cambium in some of these injured trees was capable of regeneration, and wound tissue was formed during the summer on the inside of the bark; but of course this made no union with the wood, and was of no apparent help in preserving the life of the tree. In cases of severe injury the formation of this thick callous layer caused the bark to split open and roll away, exposing the wood (Plate XIX, 1). In cases in which only a small area of bark was loosened, healing took place in the normal manner from the edges of the wound. The most severely injured trees either died late in the summer of 1914 or were removed by the owner in the spring of 1915. Photographs of some of these injured trunks are shown in Plate XIX.

REVIEW OF AMERICAN LITERATURE ON SUN-SCALD AND RELATED INJURIES

The first mention of sun-scald injury in this country is by Burrill (1887).[4] He describes a crown injury which is commonest on the sunny side of the trees. His explanation is as follows: Late growth, induced by a warm, moist autumn following a period of drouth, causes severe winter injuries in trees. These occur mechanically by freezing of the relatively large quantities of water in the cambial region; ice formation, together with shrinkage of the tissues, causes the bark to be pushed away from the wood.

Selby (1897) describes a local blighting of branches and trunk of apples and pears, known as sun-scald. It occurs most commonly on the west and southwest sides of trees, and trees leaning to the northeast suffer the most. Baldwin, Oldenburg, and King are listed as susceptible varieties.

Selby (1900) again mentions the occurrence of an injury of this sort to the southwest side of the tree. Grimes, King, and other varieties were severely injured.

Stewart, Rolfs, and Hall (1900) describe a case of "King disease" believed to be due to winter injury. The bark at the base of the trunk is dead and loose or fallen away; the injury extends from one to two feet up the trunk, occasionally up to the crotch, and is common on the southwest side but not confined to that side. Similar injuries are described as occurring on peach, apricot, and plum.

Clinton (1904) describes an injury to apple trees from four to eight years old which seems to be crown rot. It consists of dead areas in the bark at the base of the tree, most frequently on the north side, sometimes completely girdling the tree. Sudden zero weather on December 9, 1903, following an open fall, was believed to be the cause.

The same author (1905) describes similar injuries occurring in 1904. The injury was to the bark at the base of the trunk, often on one side but in some cases the trees were girdled. Isolated dead areas were found farther up the trunk. Young trees suffered the most. It is stated that late cultivation and excessive fertilization allow the trees to enter the winter in an unripened condition, rendering them more susceptible to winter injury.

Clinton again (1908) notes a "collar girdling" of peach trees due to winter injury, probably caused by the severe winter of 1907-08 in connection with the drouth of the previous summer which weakened the trees.

Macoun (1908) describes ten different types of winter injury occurring in Canada. Among these are the following:

Bark splitting, which is found usually on young trees. It is due to expansion, occurring when the trees have grown late and are succulent and there is a heavy fall of snow before the soil freezes. The snow softens the bark, and when the temperature falls suddenly the moisture in or under the bark expands in freezing and loosens the bark from the trunk or kills the cambium. Crown rot of the Gravenstein in Nova Scotia is probably the same injury.

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[4] Dates in parenthesis refer to literature cited, page 283.

Sun-scald, an injury common in northern and northeastern Ontario and Quebec. It occurs on the south and the southwest side of the trunk. The bark becomes unhealthy, dies, dries up, and falls away. The injury occurs in late winter or early spring, when warm days are followed by cool nights. It is the same as is found when frozen plants are thawed out suddenly, and is caused by constant alternate thawing and freezing.

Crotch injury, in which case the bark is dead in the crotch or on branches diverging from it. The injury is probably due to the lodging of ice in the crotch. The theory has been advanced that this ice acts as a lens in focusing the sun's rays, but the position of the limbs does not favor this view. It is more probable that the injury is due to softening of the bark by melted snow or water before freezing; the bark is also probably more tender at this point.

Selby (1908) describes injuries due to the October freeze of 1906. Trunk injuries were on the most exposed sides of the tree, the location of which varied in different localities. Late growth occurred in 1906. August and September were very warm, with a heavy rainfall. These conditions were succeeded by a severe cold period from October 10 to October 13.

The same author describes sun-scald as a common injury on the south and southwest sides of the trunk, and states that the severe midwinter temperatures of 1906-07 were the cause of the injury in that season. The occurrence of sun-scald is thus explained (page 135 of reference cited): "The temperature rise upon these sun-exposed surfaces is larger than upon less exposed portions, and accordingly the danger of stimulus to untimely activity of the living layer is much greater upon the heated side."

Morse (1909) notes that crotch injury was common following the winter of 1906-07. This injury is thought to be due to the loading of the crotches with soft snow, which alternately thawed and froze suddenly for two days in succession. The crotches would thus be filled with greater or less deposits of ice, which would radiate heat more rapidly than the parts not so covered.

Grossenbacher (1909) studied some cases of winter injury in western New York and in the Hudson Valley. The studies were made in 1909 and the injuries were then several years old. They were all of the crown rot type, occurring at the base of the tree with no reference to the points of the compass.

The same author (1912) reports studies of injuries that occurred in various parts of New York State, the majority of them in the winter of 1910-11. These injuries were in most cases to the crown of the tree. Where less than complete girdling occurred, Grossenbacher found a localization of the injury corresponding to the maximum wind exposure and the presumable direction of the prevailing wind at the time of injury. He records two other cases of injury that may be considered of sun-scald type: an injury to the southwest side of the trunks of young maples in a park near Geneva, during the winter of 1909-10; and a similar injury to young apple trees at Clyde whose trunks had been surrounded by veneer protectors, during the winter of 1910-11.

Grossenbacher ascribes the cause of crown rot to low temperatures accompanied by bark tensions set up by the swaying of trees in the wind. Rapid evaporation caused by high winds is believed to be a contributory factor. High bark tensions set up by rapid growth at crown and crotch are thought to have some effect in causing the localization of injury at these points.

Grossenbacher reports an experiment in which he thawed the bark of a tree with hot water, on a January day when the air temperature was –26° C., and swayed the tree vigorously for about a minute. Water was also poured on the crotch of a tree that was not swayed. In March the bark on these trees was found to be dead. As Chandler (1913) has pointed out, this injury was probably due to a rapid temperature fall, and was not, as Grossenbacher believes, influenced by the tensions set up by swaying the tree.

Chandler (1913) found that the tissue at the base of the trunk and at the crotches becomes hardy in the fall more slowly than does that of the upper parts of the trunk, of the secondary branches, or of the twigs, and suggests that this is the probable explanation of the localization of injury at these points.

THE FREEZING TO DEATH OF PLANT TISSUE

It seems desirable at this point to state the manner in which the killing of plant tissue by freezing is supposed to occur. The work of Goeppert (1830), Müller-Thurgau (1880), and Molisch (1897) indicates that the withdrawal of water during the freezing process to form intercellular ice crystals causes the death of the cells. Without considering theories advanced by later workers to account more exactly for the death of the protoplasm, it is sufficient for the purposes of this paper to state that when, during the freezing process, water withdrawal from a cell passes a certain limit, the cell is killed.

EFFECT OF RAPID FREEZING

Winkler (1913) found that dormant buds on the twigs of various trees that were killed if frozen twelve hours at –22° C., were not killed if kept three days at –16°, two days at –18°, three days at –20°, two days at –22°, and finally twelve hours at –25°; some remained alive even at –30°.

Chandler (1913), working with winter twigs and buds of various fruit trees, found that the rapidity of the freezing process is a factor influencing the killing. Tissue frozen rapidly (one and one-half hours to the minimum) was killed at a temperature three or four degrees higher than the same tissue when subjected to a slow (seven and one-half hours to the minimum) rate of temperature fall. Not so marked a difference was found in the case of succulent plants. Chandler found further that rapid temperature fall was much more injurious in the first part of the freezing period (from 0 to −12° C.) than in the latter part.

EFFECT OF RAPID THAWING

It was held by earlier workers that the injurious effect of freezing on plant tissue was not due to the freezing itself but to rapid thawing.

Goeppert (1830) was the first real advocate of the view that the injury is caused by the freezing process and is independent of the rate of thawing. This opinion was based on a large amount of experimental work.

Sachs (1860) conducted some experiments from which he concluded that the amount of killing was directly dependent on the rate of thawing; with plants frozen to a given temperature, those that were thawed rapidly were killed in a greater proportion than those that were thawed gradually.

Müller-Thurgau (1886), in a long series of experiments conducted with a variety of plants, found no proof that slow thawing acted to prevent injury; if the plant was killed, either rate of thawing showed it killed; if uninjured at the end of the slow-thawing process, it was also uninjured by rapid thawing.

It is interesting that Sachs' method of slow thawing was to place the frozen plants in cold water. Müller-Thurgau has pointed out that this was in reality a more rapid method than thawing in air. When the frozen plants are placed in water, a layer of ice immediately forms on their exterior, giving off heat to the tissue and consequently warming it.

Molisch (1897) conducted a large number of experiments on the effect of rapid thawing, with results similar to those obtained by Müller-Thurgau. He found a slight benefit from slow thawing in the case of fruits of apple and pear, and leaves of *Agave americana* L. With these tissues a slight further reduction in temperature was sufficient to kill, regardless of the rate of thawing.

Chandler (1913), working with a number of different plants, found no benefit from slow thawing except in the case of lettuce, and ripe fruits of apple and pear. With these tissues only a slight further reduction of temperature was needed to offset entirely the effect of slow thawing. Chandler was unable to find that increased rate of evaporation during the thawing process had any effect on the killing.

It seems strange, in view of the excellent work of Müller-Thurgau, that the idea has continued so prevalent that rapid thawing causes the death of frozen plants, and that the same plants if thawed slowly would be saved. Perhaps it is due to the wide influence Sachs has had on later botanists, and to the possibility that his work may have been more widely read than that of Müller-Thurgau. Since the publication of Chandler's work there should be no reason for any one to adhere to this view.

Special emphasis is laid on this point, since the prevailing idea regarding the occurrence of sun-scald is that it is due to rapid thawing of the tissue on the sun-exposed side of the tree on a day of extreme cold in late winter. It is proposed in this paper to discard this hypothesis at the outset as untenable.

THEORIES REGARDING THE OCCURRENCE OF SUN-SCALD

Previous to the time of Müller-Thurgau's work in 1886, sun-scald was commonly believed to be due to rapid thawing of the frozen tissue, brought about by the action of the sun. This view has also had many adherents since that time.

Müller-Thurgau mentions the injury as one often occurring on the sunny side of trees, and places in the same category common winter injuries to needles on the south side of coniferous trees, and the protection from winter injury afforded trees and shrubs which grow on the north side of buildings.

Müller-Thurgau's explanation of the occurrence of sun-scald is as follows: Metabolic changes in the plant go on in winter under the influence of high temperatures. On sunny days in winter the bark on the south side of the tree is ten centigrade degrees or more warmer than it is on the north side. The tissue on the south side will be farther out of the rest condition and thus be more sensitive to cold. Flowers of Thuja are farther developed by the end of February than in December, and are also farther along on the south side than on the north side of the tree.

Müller-Thurgau found the moisture content of the bark slightly higher on the south than on the north side of the tree in late winter. He found also that the temperature of the bark was sometimes much higher on the sunny side.

If the view expressed above is not accepted, there remains the possibility that the tissue on the southwest side of the trunk may become tenderer in late winter due to repeated alternate freezings and thawings. Winkler (1913) found that by subjecting the twigs of several deciduous trees to repeated freezings and thawings he rendered them more susceptible to injury by freezing. Since the tissue on the southwest side of a tree trunk must be subjected to more repeated freezings and thawings than the tissue on the northeast side, it is possible that it may thus become tenderer.

Chandler (1913), from the results obtained in the comparison of the effects of rapid and of slow freezing, has suggested another possibility. On a cold, sunny day in late winter, the tissue on the sun-exposed side of a tree may become thoroly thawed out while that on the opposite side remains at or near the atmospheric temperature, which may be very low. Under these circumstances, when the sun's rays are withdrawn from the tree in late afternoon the temperature of the warmed area of the bark will fall rapidly to that of the atmosphere. As injury is greater when the temperature fall is rapid, especially in the first part of the freezing period, it is conceivable that the temperature of the tree may fall during the night to a point low enough to kill the tissue on the southwest side of the trunk, while that on the northeast side, protected by a slower temperature fall, will remain uninjured.

Other explanations are those offered by Burrill (page 242 of this bulletin); by Hartig (1900), who suggests that the bark becomes so warmed by the sun's rays in certain places that it expands considerably and separates from the wood; and by Sorauer (1909), who ascribes the phenomenon to tension differences in the tissues, set up by sudden temperature changes.

OBSERVATIONS AND EXPERIMENTS

Sun-scald injury may be considered a form of direct freezing to death caused in one of two ways: (1) an increased tenderness in the tissue on the sunny side of the trunk in late winter causes it to kill at a temperature not low enough to injure the still dormant tissue of the shaded side; or (2) the tissue on the sunny side kills at a higher temperature, due to the more rapid temperature fall that may take place after a cold, sunny day in late winter. It is of course possible that both these factors may be operative in causing the injury.

In order to test the relative value of these two hypotheses, some observations and experiments were made during the winters of 1913-14 and 1914-15. In the experiments reported below, the cambium was taken as the critical tissue, since in observed cases of sun-scald the cambium suffers severe injury, and without injury to the cambium and outermost xylem the bark would not separate from the wood nor would any injury beyond easy repair occur.

Temperatures that may occur in winter on the sun-exposed parts of the trunk

During the winters of 1913-14 and 1914-15, records were taken of the temperatures of the cortex and the outer sapwood on sun-exposed and shaded sides of the trunks of several apple trees, in order to ascertain just what temperature conditions may arise under given circumstances. The temperatures were taken with ordinary mercury thermometers of the chemical type. Since the result desired was a comparison of temperatures, looking for fairly wide differences, no attempt was made to standardize these thermometers, but they were carefully compared before and after using and were found to check with one another within one-half of one degree. These thermometers were graduated in degrees Fahrenheit between –20° and +120°. In the following tables the readings have been transformed to the centigrade scale, which accounts for the decimal. No attempt was made to read the thermometers more closely than to one-half of a graduation interval.

The manner of insertion of the thermometers was as follows: A hole was bored tangentially into the tree trunk so that when the thermometer bulb was inserted it lay partly in the inner cortex and partly in the outer sapwood, while the stem projected horizontally or was slightly inclined upward. The hole was only very slightly larger than the diameter of the bulb, and after insertion of the thermometer the outer opening was sealed around the thermometer stem with paraffin. The thermometer bulb was thus entirely within the tissue, and it is not believed that the unavoidable small air space around the bulb introduced any material error into the observations.

Air temperatures were taken by means of a thermometer hung against the northeast side of the trunk just above the thermometer inserted on that side.

TABLE 1. TREE TEMPERATURES ON THE SOUTHWEST AND NORTHEAST SIDES UNDER CLOUDY CONDITIONS, 1914

Date	Hour*	Temperatures (degrees centigrade)		
		Southwest side	Northeast side	Air
Tree no. 3				
January 15	11.00	—6.9°	—7.5°	—5.5°
16	**1.30**	3.3°	2.8°	2.6°
17	**1.30**	—1.9°	—3.0°	—3.9°
19	**1.00**	—3.9°	—3.9°	—2.5°
20	11.40	0.0	0.0	1.1°
21	**1.00**	0.0	0.0	—2.2°
23	**1.10**	—2.2°	—2.2°	0.0
24	**1.10**	—0.5°	—0.5°	4.4°
Tree no. 38				
January 16	**1.40**	3.9°	3.3°	2.2°
17	**2.00**	—2.8°	—3.6°	—4.7°
19	**1.15**	—3.3°	—3.3°	—2.8°
20	**12.20**	0.0	0.0	1.7°
21	**1.20**	—0.3°	0.0	—3.9°
23	**1.30**	—0.5°	—1.1°	0.0
24	**1.30**	0.0	—0.5°	4.4°

* Forenoon records are in light-faced type, afternoon records in black-faced type.

For the observations of 1913-14 two trees in the university orchards at Ithaca were selected. Tree no. 3 was a large old seedling tree with a trunk about three feet in diameter. Tree no. 38 was a twenty-years-old Baldwin tree with a trunk diameter of about ten inches. The thermometers were inserted about three feet from the ground in each case.

At the beginning of the observations, readings were taken on cloudy days as well as on sunny days, in order to determine whether any difference in temperature might occur due to any other influence than that of the sun. Some of these readings are given in table 1.

Temperatures that may be reached on a bright day by the tissue on the sun-exposed side of a tree are shown in table 2:

TABLE 2. TREE TEMPERATURES ON THE SOUTHWEST AND NORTHEAST SIDES ON SUNNY DAYS, 1914

Date	Tree no.	Hour*	Temperatures (degrees centigrade)		
			Southwest side	Northeast side	Air
January 14	3	**3.00**	—2.8°	—12.2°	—12.2°
26	3	**2.25**	1.1°	— 2.8°	— 1.4°
26	38	**3.10**	—0.5°	— 2.5°	— 1.9°
February 2	3	**1.30**	12.2°	— 1.1°	— 0.5°
2	38	**2.00**	7.7°	— 0.3°	0.0
3	3	**1.35**	15.0°	2.8°	9.4°
3	38	**1.15**	15.5°	0.0	5.0°
4	3	**1.05**	12.8°	0.8°	1.6°
4	38	**1.30**	11.7°	1.7°	2.2°
8	3	**2.10**	—0.5°	— 4.4°	— 6.7°
8	38	**2.30**	—1.7°	— 3.9°	— 6.1°
9	3	**12.50**	—4.4°	— 9.4°	— 8.3°
9	38	**1.05**	—5.6°	— 8.3°	— 8.3°
13	3	**1.00**	—6.4°	—15.0°	—11.7°
13	38	**1.20**	—1.1°	—10.0°	—12.2°
15	3	**2.50**	3.9°	— 9.4°	—12.2°
15	38	**3.20**	1.4°	— 8.3°	—12.2°
23	3	**1.00**	—6.4°	—11.4°	—14.4°
23	38	**1.25**	—4.4°	—11.4°	—16.1°
24	3	**1.00**	—2.8°	—16.1°	......
24	38	**1.20**	—1.1°	—13.9°	—16.1°
25	3	**12.55**	1.7°	— 9.7°	— 5.6°
25	38	**1.15**	3.9°	— 2.8°	— 5.3°
26	3	11.00	—1.9°	—10.0°	......
March 10	3	**1.30**	20.5°	0.0	1.1°
10	38	**1.50**	27.2°	2.2°	2.2°
12	3	**12.50**	15.0°	— 3.3°	— 4.4°
12	38	**1.15**	16.7°	0.0	— 4.4°
24	3	**1.15**	12.2°	1.7°	3.9°
24	38	**1.35**	11.1°	2.2°	2.2°
25	3	**1.00**	11.1°	5.0°	8.9°
25	38	**1.25**	10.6°	6.1°	7.8°

* Forenoon records are in light-faced type, afternoon records in black-faced type.

It is believed that in table 2 are found some of the highest temperatures reached in these particular trees during the three months of January, February, and March, 1914. It will be seen that the tissue on the southwest side of the tree is often much warmer than that on the northeast side. It does not, however, seem possible that these temperatures are high enough to start the tissue into activity. A significant fact is that on four days — January 14, and February 13, 15, and 24 — the tissue on the southwest side of the tree was nearly, if not quite, thawed out, while that on the northeast side was at a very low temperature. In this connection table 3 is of interest, showing temperatures in an old seedling tree, with a trunk diameter of about eighteen inches, at Clinton, New York, on January 1 and 2, 1914. The observations here recorded also give some idea of the possible rate of temperature fall on the southwest side when the sun leaves that part of the tree.

TABLE 3. TREE TEMPERATURES OBSERVED AT CLINTON, NEW YORK, AND AT ITHACA, NEW YORK, 1914

Date	Tree	Hour*	Temperatures (degrees centigrade)		
			Southwest side	Northeast side	Air
January 1.......	Old tree at Clinton	**3.00** **3.30** **5.00**†	8.9° 8.3° 0.0	—4.4° —4.4° —4.4°	—5.6° —5.6° —8.3°
January 2.......	Old tree at Clinton	11.00	7.2°	—8.3°	—10.0°
January 2.......	Tree no. 3 at Ithaca	**3.00** **4.45**‡ **5.15**§	—2.8° —7.8° —9.4°	—12.2° —15.0° —15.3°	—12.2° —15.6° —16.1°

* Forenoon records are in light-faced type, afternoon records in black-faced type.
† A few minutes after sundown.
‡ Sun just down.
§ Thirty minutes after sundown.

Temperatures observed during the winter of 1914-15

Temperature observations were continued during the winter of 1914-15. Since it was believed that in the case of injury to the trees in the Everett orchard, mentioned on page 240, the indirect causal factor was the high temperature induced by the black color of the tarred trunk, some records were obtained from trees similarly blackened. Later in the winter records were taken from a whitewashed trunk, in order to learn whether a coating of whitewash would prevent an injurious rise in temperature. A space of about two feet up and down the trunk was tarred on November 23, 1914. The lower edge of this tarred space was two feet above the ground. The thermometers were inserted into the middle of the tarred space. An additional thermometer was inserted six inches above the tarred space and on the southwest side of the tree. The whitewash was applied to a similar area on another tree. The whitewash gradually weathered off and was renewed once. Part of the time during which the records were taken the whitewash was in a somewhat washed-off condition. This was purposely allowed, in order to determine the effect of a poor coating of whitewash, since this would more nearly approximate conditions met with in the practical use of whitewash to prevent sun-scald.

Later in the winter thermometers were inserted into two small trees, whose trunk diameter was about three inches. In this case the whole of the thermometer bulb could not be as nearly contained in the cortex and outer sapwood as in the larger trees; the central part of the bulb was separated from the outer air by a layer of sapwood and bark about one-fourth inch thick. This would lead to error in the readings, but it may be assumed that the temperature of the cambial area would be if anything higher than the readings obtained.

The records for 1914-15 were taken at Ithaca from the following trees:

(a) Tree no. 6 — an old seedling tree in the Blair orchard, with a trunk diameter of about three feet. A part of the trunk was tarred and thermometers were placed in the tarred space on the southwest and northeast sides of the trunk, with a third thermometer six inches above the upper limit of the tarred space on the southwest side.

(b) Tree no. 3 — an old seedling tree in the Blair orchard, from which records were taken in 1914. Thermometers were placed on the southwest and northeast sides of the trunk, about three feet from the ground.

(c) Tree no. 0 — an old seedling tree in the Blair orchard, with a trunk diameter of about two and one-half feet. A space on the trunk was whitewashed, and thermometers were placed in the center of the whitewashed area on the southwest and northeast sides and about three feet from the ground.

(d) Tree no. 24 — of the variety Gano, in the university orchard, with a trunk diameter of three inches. On January 30 thermometers were placed on the southwest and northeast sides about three feet from the ground.

(e) Tree no. 25 — a similar tree to no. 24. Thermometers were placed on the southwest side of the trunk in the center of a tarred space.

The air temperatures were taken by means of maximum and minimum thermometers, one hung on the northeast side of the trunk of tree no. 6 in the Blair orchard, the other on the northeast side of a large post near trees no. 24 and no. 25 in the university orchard.

The records obtained during the winter of 1914-15 are given in table 4. The readings were all taken on bright days.

TABLE 4. TEMPERATURES (IN DEGREES CENTIGRADE) OBSERVED ON DIFFERENT SIDES OF TREES TREATED WITH TAR AND WITH WHITEWASH, AND OF UNTREATED TREES, DURING THE WINTER OF 1914–15

Date	Blair orchard									University orchard					Notes
			Tree no. 6			Tree no. 3		Tree no. 0				Tree no. 24		Tree no. 25	
	Hour of reading*	Air temperature	North-east side. Tarred space	South-west side. Above tarred space	South-west side. Tarred space	North-east side	South-west side	North-east side. White-washed	South-west side. White-washed	Hour of reading*	Air temperature	North-east side	South-west side	South-west side. Tarred	
December 15	7.00	—17.2°	—13.9°	—12.2°	—13.9°	—13.9°	—13.9°	......	......	......	......	......	......	......	Minimum for night, —20°
15	**1.45**	—10.0°	— 5.0°	— 0.9°	— 0.9°	— 7.2°	— 3.1°	......	......	......	......	......	......	......	
16	**1.45**	— 6.1°	— 5.0°	— 0.3°	4.1°	— 6.7°	— 1.1°	......	......	......	......	......	......	......	
17	9.00	—15.0°	—11.1°	—10.0°	—10.6°	—12.2°	—11.1°	......	......	......	......	......	......	......	Minimum for night, —16.1°
17	**1.30**	— 5.6°	— 4.4°	2.2°	7.8°	— 6.7°	1.1°	......	......	......	......	......	......	......	
18	**1.30**	— 6.1°	— 5.3°	0.6°	4.2°	— 7.2°	— 1.1°	......	......	......	......	......	......	......	
19	7.30	— 3.9°	— 5.3°	— 4.4°	— 4.4°	— 5.9°	— 5.3°	......	......	......	......	......	......	......	Minimum for night, —11.1°. Grew warmer in night
January 5	**1.15**	1.1°	— 0.9°	5.6°	10.0°	— 1.9°	4.4°	......	......	......	......	......	......	......	
7	**1.15**	4.4°	4.4°	8.9°	11.9°	......	6.9°	......	......	......	......	......	......	......	
15	**1.00**	3.9°	3.3°	16.1°	20.5°	1.7°	11.1°	0.6°	2.2°	......	......	......	......	......	
22	**1.00**	— 7.2°	— 6.1°	2.5°	6.7°	......	2.2°	— 6.1°	— 3.9°	......	......	......	......	......	
26	**1.00**	— 0.6°	— 1.1°	12.8°	21.1°	......	11.1°	— 4.4°	0.0	......	......	......	......	......	
29	**1.40**	— 7.2°	— 3.9°	— 1.7°	1.7°	......	— 3.3°	— 7.2°	— 5.3°	......	......	......	......	......	
30	8.30	—13.9°	—12.8°	—12.8°	—12.8°	—13.9°	—12.8°	—13.3°	—13.3°	......	......	......	......	......	Minimum for night —17.2°
30	**1.40**	— 5.6°	— 4.7°	5.3°	12.2°	— 8.3°	2.2°	— 8.9°	— 3.9°	**2.00**	— 5.6°	—2.2°	— 3.3°	......	
30	**2.20**	— 5.6°	— 4.9°	6.7°	13.9°	— 8.3°	4.4°	— 8.9°	— 2.8°	**2.30**	— 5.6°	—2.2°	4.4°	......	
30	**2.40**	— 6.7°	— 4.9°	6.7°	14.2°	— 7.8°	4.7°	— 8.6°	— 2.2°	......	......	......	......	......	
30	**3.40**	— 7.8°	— 5.6°	2.8°	7.2°	— 8.3°	2.2°	— 8.9°	— 2.5°	......	......	......	......	......	
February 4	**2.45**	0.0	— 0.6°	9.4°	17.8°	— 3.3°	7.2°	— 4.1°	1.1°	**2.55**	0.0	— 0.3°	13.3°	17.8°	
4	**4.35**	— 4.4°	— 2.2°	2.8°	5.6°	— 3.9°	1.7°	— 4.4°	— 0.6°	**4.45**	— 4.4°	0.0	7.2°	9.4°	
10	7.15	—11.7°	—10.0°	— 8.9°	— 9.4°	—10.6°	— 9.4°	—10.0°	—10.0°	7.25	—11.7°	—11.7°	—11.7°	—11.7°	Minimum for night, —12.2°
10	**2.00**	— 1.7°	— 1.1°	18.0°	29.0°	— 3.9°	15.0°	— 6.7°	— 0.6°	**2.15**	— 1.7°	— 0.9°	19.7°	26.6°	
10	**9.00**	— 7.2°	— 6.1°	— 2.2°	— 2.8°	— 7.2°	— 2.8°	— 7.2°	— 6.1°	**9.10**	— 8.0°	— 6.7°	— 6.9°	— 7.8°	
19	**2.15**	3.9°	0.0	22.2°	31.1°	— 1.7°	17.2°	— 2.2°	5.0°	......	......	......	......	......	
20	**2.05**	6.1°	1.7°	25.0°	33.3°	0.0	21.7°	— 0.6°	6.1°	**2.20**	......	11.1°	21.7°	25.0°	
March 8	4.45	— 1.7°	1.1°	12.2°	17.8°	......	9.4°	— 1.7°	6.4°	**4.45**	— 3.3°	1.7°	11.7°	......	

* Forenoon records are in light-faced type, afternoon records in black-faced type.

Some additional facts may be gained from a study of table 4. The black color of the tarred surface where exposed to the sun seems to be very effective in raising the temperature of the inner bark and the outer sapwood much above that of the air, and also considerably above that of the similarly sun-exposed but untarred surface. Conduction from this warmed area was sufficient to warm the tissue six inches above the upper limit of the tar to a temperature higher than that of the untarred, sun-exposed trunk. Probably this conduction is also felt in the direction of the circumference, since the temperatures on the northeast side of the blackened tree were slightly higher than appears normal for the shaded side. This would no doubt have been more noticeable with a smaller tree, but unfortunately this point was not ascertained. On the other hand, the coating of whitewash, even when considerably weathered (as shown by readings subsequent to February 10), seemed effective in preventing a considerable rise in temperature on the sun-exposed side of the trunk.

The temperature of the shaded side of the trunk is very rarely exactly the same as the temperature of the air at the time of the reading, but is slightly lower if the temperature of the air is and has been rising, and higher if the air temperature has been falling. This is what naturally would be expected — that the tree temperature would follow the air temperature rather closely, but would not undergo as rapid changes.

The early morning readings deserve consideration. On December 14, the air temperature fell rapidly during the afternoon and reached a minimum of –20° C. sometime in the night. At seven o'clock in the morning on December 15, the air temperature had risen but slightly above the minimum, namely, to –17.2°. The lowest tree temperature at this hour was –13.9°. It appears that the tree temperature had not kept pace with the rapid temperature fall of the atmosphere, and that –13.9° was the minimum reached by the tree during that night. Subsequent observations on other days, made in the morning before the air had warmed much above the minimum for the night, confirm this point. On December 17, the minimum for the previous night was –16.1°; at nine o'clock in the morning the air temperature was –15°; the lowest tree temperature was –12.2° (on the northeast side of tree no. 3), and the highest was –10° (on the southwest side of tree no. 6). On December 19, the lowest atmospheric temperature for the previous night was –11.1°, reached at ten o'clock; about midnight the atmospheric temperature began to rise, and at half past seven had reached –3.9°; the tree temperatures at that hour were fairly close to the air temperature. On January 30, the minimum for the previous night was –17.2°; at half past eight in the morning the air temperature had risen to –13.9°, but the tree temperatures were yet considerably above the minimum for the night, the lowest tree temperature being –13.9° and the highest –12.8°.

Probably the explanation of this phenomenon lies in the fact that the large trunk contains a considerable quantity of stored heat, which operates to prevent a rapid temperature fall in the tree tissue. In the case of the temperatures discussed above, the trees were all large and old, with thick bark and great diameter of trunk. It was thought probable that a tree with a trunk diameter of only three or four inches would follow the changes in atmospheric temperature much more closely. This seems to be true. On February 10, the minimum air temperature for the previous night was –12.2°. At a quarter past seven in the morning the air temperature was –11.7°; the lowest tree temperature in the old trees was –10.6°, and the highest –8.9°, on the southwest side of the trunk; the thermometers in the young trees all stood at –11.7°, the then air temperature. It is not improbable that the young trees had reached the air minimum and again warmed up, following the air temperature closely. Another observation on this point was taken at nine o'clock in the evening on February 10. An examination of the records for that hour, together with those for two o'clock on the same afternoon, indicates that the younger trees, with smaller trunk diameter, follow the atmospheric temperature fall more closely than do the large old trees. In this connection it is interesting to recall that trees with a trunk diameter of less than a foot are more subject to sun-scald than are larger trees. Rarely, if ever, does sun-scald occur on large old trees. As will be seen later, in artificial freezings tissue from old trees does not seem particularly hardy as compared with that from young trees.

It will also be noticed that temperatures on the southwest side of the trunk were somewhat higher in the young trees than in the old ones. This was perhaps due to the difference in bark color and thickness; the bark on the old trees was thick and light gray, while that on the young trees was thinner and of a reddish brown color.

In young trees the temperature on the northeast side of the trunk rises above the air temperature on sunny days, tho not so high as that on the southwest side. This is not true in the case of old trees. The difference is probably due to the greater ease of conduction thru and around the smaller trunk.

These differences in behavior of large and small tree trunks are even more evident in table 5, which records temperatures observed at Geneva, New York, February 14, 1916. The trees compared were a large old Baldwin, and a young Century whose trunk diameter was about four inches. Especially remarkable is the rapidity of temperature fall in the small trunk after sundown.

TABLE 5. COMPARATIVE TEMPERATURE RECORDS FROM LARGE AND SMALL TREES, FEBRUARY 14, 1916

Hour of reading (p. m.)	Temperature (degrees centigrade)			
	Small tree, northeast side	Small tree, southwest side	Large tree, southwest side	Air
2.00	— 3.3°	1.1°	....	11.1°
3.00	— 5.0°	5.5°	....	12.5°
4.00	— 7.2°	3.9°	....	—13.5°
5.00*	— 9.4°	— 0.3°	3.9°	—14.4°
6.00†	—18.3°	—14.4°	—3.3°	—22.2°

* Thirty minutes before sundown.
† Thirty minutes after sundown.

One fact which cannot be readily explained is that the temperature on the northeast side of tree no. 3, both in 1914 and in 1915, was often slightly lower than that of the air. It was thought that possibly some error had been made in the original comparison of thermometers; but the thermometer in this place was twice broken and replaced, and it does not seem probable that the same error would occur three times in standardizing.

Some of the more striking records from tables 2, 3, and 4 are grouped together in table 6. The readings are expressed in degrees Fahrenheit, since the Fahrenheit scale is the one commonly employed in reporting atmospheric temperatures.

A comparison of the date of awakening and relative hardiness of the cambial area on the northeast and southwest sides of the trunk

Müller-Thurgau, as has already been stated, suggests that the occurrence of sun-scald may be due to an early awakening, and consequent increased tenderness, of the tissue on the southwest side of the tree, brought about by the action of the sun in late winter. The temperature records obtained do not offer much support for this hypothesis, but it was considered worth while to obtain some evidence for or against it.

Cuttings, including bark, cambium, and outer sapwood, were taken in 1914 from a large old seedling tree (no. 5) in the Blair orchard, and from a young Northern Spy tree (no. 17) in the university orchard whose trunk diameter was about three inches. The cuttings were taken from approximately the same height on the southwest and northeast sides of the trunk, on the following dates: January 20, March 16, April 8, May 2, May 16, and May 31. They were fixed, infiltrated, and imbedded in collodion, and sections were made and examined microscopically for signs of cambial activity.

TABLE 6. STRIKING DIFFERENCES IN TEMPERATURES ON SUN-EXPOSED AND SHADED SIDES OF TREES

Date	Temperatures (degrees Fahrenheit)									
	Air	Large tree		Large tree, tarred		Large tree, whitened		Air	Medium-sized tree	
		Northeast side	Southwest side	Northeast side	Southwest side	Northeast side	Southwest side		Northeast side	Southwest side
(1914)										
January 2...	10°	10°	27°	....	....	....	....	....	....	....
January 13...	11°	5°	20.5°	....	....	....	....	10°	14°	30°
February 15...	10°	15°	39°	....	....	....	....	10°	17°	34.5°
February 24...	....	3°	27°	....	....	....	....	3°	7°	30°
December 15...	14°	19°	26.5°	23°	30.5°	....	....	....	....	....
									Small tree	
									Northeast side	Southwest side
(1915)										
January 22...	19°	....	36°	21°	44°	21°	25°	....	....	....
January 30...	20°	18°	40.5°	23°	57.5°	16.5°	28°	22°	28°	40°
February 20...	43°	32°	71°	35°	92°	31°	43°	43°	52°	71°

The cambium appeared in its winter condition in all sets of cuttings up to those taken on May 2. In the cuttings taken on this date the cambium appeared to be beginning activity and a few recently formed tracheal elements and xylem cells were in evidence. There was no discernible difference on this date in the condition of the cuttings from the opposite sides of the trunk. If the cambium on the southwest side started into activity before that on the northeast side, this must have occurred sometime between April 8 and May 2. In this latitude, temperatures sufficiently low to cause injury to the awakening cambium could hardly be expected to occur so late in the spring as this. On May 31 considerable new xylem had been laid down inside the now thoroly active cambial ring. Again no difference could be detected between cuttings from the southwest and the northeast side of the trunk.

In 1915, cuttings that were taken for artificial freezing from several trees as late as April 13 were incidentally examined for signs of cambial awakening, but no such signs were observed on that date. The next opportunity for observation on this point was at Peru, Clinton County, on May 1. At that date growth had begun on both sides of the trunk. The season at Ithaca is a few days in advance of the season at Peru, so that observations made in the two places are fairly comparable. Brown (1912), in studies on growth in *Pinus rigida* Mill., found no difference in the time of cambial awakening on the north and south sides of the trunk.

Since there is doubtless some not thoroly understood change that takes place in the protoplasm before growth begins, it was believed that an increased tenderness in the cambium might easily be observed before growth itself, and that this would be a more accurate test of Müller-Thurgau's hypothesis. Any increased tenderness in the cambium could by careful manipulation be detected by artificial freezing.

At different times in 1914 and 1915, tissue from various old and young trees was subjected to artificial freezing in order to determine this point. Cuttings were taken from the southwest and northeast sides at the same height on the trunk — from two and one-half to three feet from the ground. Each cutting included bark, cambium, and a thin layer of sapwood, and was removed with extreme care so as to avoid mechanical injury to the tissues, which might introduce error into the results. The cuttings were shaved down as nearly as possible to the same thickness (from two to two and one-half millimeters) and cut into pieces of the same area, three pieces being made from each cutting. The pieces prepared in 1914 were about six millimeters square; those prepared in 1915 were punched out with a cork borer the diameter of which was six millimeters. Each piece thus represented a small area of the cambium, with equal thicknesses of cortex and xylem on either side. The pieces were made small in order that temperature changes in them could take place evenly and rapidly; it was believed that with pieces of this size close to or in contact with the thermometer bulb, the thermometer reading would be a fairly accurate representation of the internal temperature.

In the experiments conducted in 1914 the pieces were firmly tied with fine thread to the thermometer bulb, one on each side. The thermometer was inserted thru a cotton plug into a test tube in such a manner that the lower end of the bulb just cleared the bottom of the test tube. For the first part of the freezing process the tube was inserted into a larger tube, similarly plugged in order to secure insulation by the dead-air space between the two tubes. The larger tube was then placed in an earthen vessel containing, first ice, then ice and salt. The proportion of salt in the freezing mixture was gradually increased each time the mixture was replaced. When a certain minimum temperature was reached, the larger outer tube was removed and the inner tube placed directly in the freezing mixture. By means of these precautions it was possible to regulate the temperature fall so that it was even and slow. This was extremely desirable, since, as Chandler (1913) has shown, a rapid temperature fall, especially in the first part of the freezing, is markedly injurious. As the object sought was to determine any difference in hardiness between the two samples of tissue, a too rapid rate of temperature fall might be a source of too great error.

In these experiments it usually took from six and one-half to seven hours to reach the minimum temperature obtainable with salt and ice. The tube was then removed, and placed in an insulated vessel containing a mixture of crystallized calcium chlorid and ice (the ice and calcium chlorid having been previously cooled to the temperature of salt and ice). The proportions of this mixture were also varied, but it was not possible to prevent a fairly rapid temperature fall at this stage of the freezing. Since, however, it is in the early part of the freezing that the effect of rapidity of fall is most noticeable, this was not regarded as a great source of error. The temperature was read and recorded every fifteen minutes up to the time of the employment of calcium chlorid, and from then on every five minutes. The thermometers used in 1914 were mercury thermometers similar to those employed in taking tree temperatures. These were later compared with the standardized thermometers used in 1915. The thermometers used in 1915 were two spirit thermometers graduated in degrees centigrade from −50° to +80°. These were standardized by the United States Bureau of Standards.

The apparatus used for the freezing work in 1915 is shown in figure 61. Essentially it consisted of three concentric tin cylinders, of which the innermost one constituted a chamber for the material to be frozen, and the outer two were containers for the freezing mixture. These three cylinders were inclosed on sides and bottom in an outer chamber filled with insulating material. A shaft passing down into the central cylinder bore near its lower end a small tin disk, on the upper surface of which were a number of small pin points. The material to be frozen was placed on these points. The disk was made to revolve slowly during the freezing process, by means of a pulley of large circumference attached to the upper end of the shaft and driven by a belt from a small, low-speed electric motor. This was in order to make sure that the various pieces of tissue would be subjected to the same temperatures and to the same rate of temperature fall, since all parts of the central cylinder might not be at exactly the same temperature.

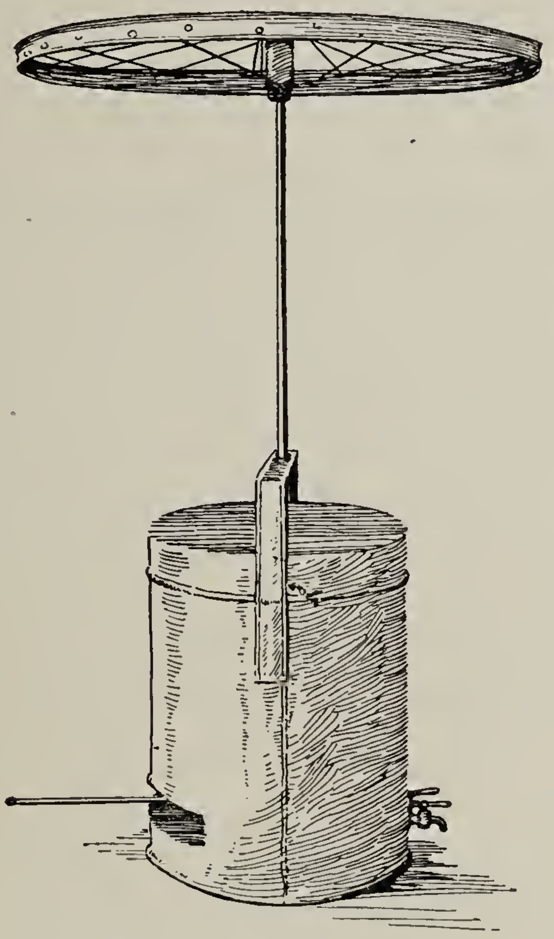

FIG. 61. FREEZING MACHINE USED FOR ARTIFICIAL FREEZING EXPERIMENTS

A recess was cut into the lower part of the apparatus at one side, as far as the wall of the central cylinder, allowing a thermometer to be inserted thru a cork in such a manner that the bulb was wholly within the central cylinder and just beneath the revolving disk, while the stem was wholly in the outer air. By means of this arrangement the temperature could be read whenever desired without disturbing either thermometer or tissue. The apparatus was made rather deep in order to allow room for insulation of wool felt which was packed in the upper parts while the freezing was going on. The whole apparatus was covered by an easily removable lid. The freezing-mixture chambers were provided with drainpipes and stopcocks.

In the freezing process the outer cylinder was filled with ice-and-salt mixtures, with gradually increasing proportions of salt, until the minimum temperature that could be obtained with this mixture was reached, the dead-air space of the second cylinder meanwhile acting as insulation to prevent too rapid temperature fall. A calcium-chlorid-and-ice mixture was then placed in the second cylinder until the desired temperature was reached.

One defect was observed with this machine when low temperatures were desired. As is well known, a mixture of calcium chlorid and ice is not particularly efficient as compared with salt and ice. In this apparatus its efficiency was still further impaired by the heat lost in freezing the water that was unavoidably present in the ice-and-salt mixture of the outer chamber.[5] In the later freezings of 1915, when a temperature below −28° C. was desired it was necessary to place the tissue in thin-walled glass shells attached to the shaft near its lower end, and when the minimum of the machine was reached to remove these quickly and place them in a calcium-chlorid-and-ice mixture contained in an insulated vessel. In this case the thermometer bulb was placed directly in the mixture. Several vessels were employed, each with a mixture whose temperature was slightly lower than the preceding, so that the temperature fall could be regulated to comparative slowness.

The temperatures were read and recorded at the same intervals as in the 1914 experiments, and the same rate of temperature fall was maintained.

Before each set of freezings, preliminary freezings were run with tissue from the north or the east side of the trunk until the killing point of the cambium was determined; then the tissue to be compared was carried down to that point — or usually to a degree or two short of that point, as any differences in hardiness could more readily be noted if the killing was partial. Indeed, when, as was often the case, there was almost no injury and it was at the same time known that the killing point had been all but reached, the results were considered as valuable as when there was more evident injury; since if the insolated tissue were noticeably tenderer, it would certainly kill under such conditions.

The amount of injury was determined by examination under the low power of the microscope. The edges of the pieces were trimmed and free-hand sections were cut across the center of the pieces in every case, as occasionally unavoidable mechanical injury to the outer edge of a piece would increase the amount of killing in that region.

As is well known, the anatomical cambium consists of several layers of cells, of which properly only the central layer is the true, or physiological, cambium. In these freezing experiments the tissue first injured was the layer of cambial cells next to the last-formed layer of xylem cells, in other words, the youngest wood elements. Occasionally the interfascicular cambium seemed to be the tenderest tissue. Since severer injury was marked by extension of the discolored line to include more layers of the anatomical cambium until complete killing showed them all discolored, the amount of injury could be readily estimated in percentage and in many cases is so expressed in the tabulated results.

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[5] This defect in the apparatus could be remedied easily by constructing the outer freezing chamber with false walls so that the ice-and-salt mixture could be removed and the space filled with wool-felt insulation. With this improvement it is believed that the machine would be efficient to as low temperatures as are ever desired.

Before examination the pieces were left for from twenty-four to forty-eight hours after the freezing, when the characteristic brown discoloration of cell contents caused by frost injury could be recognized readily. Several unfrozen pieces of tissue were similarly left and examined each time, but in no case was the discoloration present in them. Of course the time when such freezings should be run in order to determine the point in question is late winter and early spring; but in order to throw light on the general question of hardiness, freezings were run at intervals thruout the entire dormant period, and the results are thought to be of sufficient interest to be reported here. They are given in table 7:

TABLE 7. RECORD OF ARTIFICIAL FREEZING EXPERIMENTS TO DETERMINE RELATIVE HARDINESS OF TISSUE OF THE TRUNKS OF TREES IN 1914-15

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
1	(1914) Jan. 28	Northeast side, 20-years-old Baldwin tree no. 38	3¼	—20.6°	30	Evident injury to cambium, slight injury to cortex, no injury to xylem
		Southwest side, same tree				Injury not noticeably different
2	Jan. 30	Northeast side, old seedling tree no. 7	7	—20.0°	30	Slight injury to cambium
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 3	7	—20.6°	30	Very slight injury to cambium
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 17	7	—21.0°	30	No injury
		Southwest side, same tree				No injury
3	Feb. 2	Northeast side, old seedling tree no. 7	7	—20.6°	45	No injury
		Southwest side, same tree				No injury
		Northeast side, old seedling tree no. 6				No injury
		Southwest side, same tree				No injury
4	Feb. 21	Northeast side, old seedling tree no. 4	6¾	—22.2°	Warmed immediately	Slight injury to cambium and cortex, very slight injury to xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 7				Same
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 18				Injury as above, but less injury to cambium
		Southwest side, same tree				Same
5	Feb. 27	Northeast side, old Bellflower tree no. 9	7¼	—20.0°	30	Severe injury to cambium, slight to medullary rays of cortex
		Southwest side, same tree				Almost no injury
		Northeast side, young Gano tree no. 20				Very slight injury to cambium

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
5	(1914) Feb. 27	Southwest side, same tree	7¼	—20.0°	30	Same
		Northeast side, young Gano tree no. 21				Same
		Southwest side, same tree				No injury
		Northeast side, young Northern Spy tree no. 22				No injury
		North side, old Bellflower tree no. 9				No injury
		North side, tree no. 22	½	—20.0°	30	No injury
		North side, tree no. 9				No injury
6	Mar. 19	Northeast side, old tree, variety unknown, no. 39	7	—28.0°	60	Complete injury to cambium, severe to cortex, slight to xylem
		Southwest side, same tree				Same
		Northeast side, old tree, variety unknown, no. 40				Same as above, but slightly less injury to cambium
		Southwest side, same tree				Same
		Northeast side, old tree, variety unknown, no. 41				Complete injury to cambium, severe to cortex, slight to xylem
		Southwest side, same tree				Same
		North side, old tree no. 41	2½	—18.3°	30	Severe injury, not noticeably different from that of slowly frozen tissue
		North side, old tree no. 41				
		North side, old tree no. 40				
7	Mar. 28	Northeast side, old seedling tree no. 8	6	—26.1°	45	Slight injury to interfascicular cambium and medullary rays
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 11				No injury
		Southwest side, same tree				No injury
		Northeast side, old seedling tree no. 5				No injury
		Southwest side, same tree				No injury
		Northeast side, old seedling tree no. 13				Slight injury to interfascicular cambium and medullary rays, slight injury to outer xylem next to cambium
		Southwest side, same tree				Slight injury to interfascicular cambium and medullary rays
8	Nov. 11	Six pieces from old tree no. 39	6	—11.1°	60	No injury
9	Nov. 14	Old seedling tree no. 1	10	—21.1°	30	Injury severe to xylem, less severe to cortex. No injury to cambium
10	Nov. 16	Old seedling tree no. 1, crown, 4 inches above soil	6¾	—21.7°	5	95 per cent* injury to cambium, very little to cortex or xylem

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* Estimate from microscopic examination.

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
10	(1914) Nov. 16	Same tree, trunk, 2½ feet up	6¾	—21.7°	5	Very slight injury to cambium, slight to cortex and xylem
		Same tree, crown, 4 inches above soil	7	—23.9°	30	All cambium injured
		Same tree, trunk, 2½ feet up				75 per cent injury to cambium
11	Nov. 21	Northeast side, old seedling tree no. 2	8	—21.2°	30	15 per cent injury to cambium
		Southwest side, same tree				10 per cent injury to cambium, considerable to cortex and xylem
		Northeast side, old seedling tree no. 4, trunk tarred Oct. 23				No injury to cambium
		Southwest side, same tree				No injury to cambium
		Northeast side, old seedling tree no. 8, trunk tarred Oct. 23				Very slight injury to cambium, considerable to cortex, less to xylem
		Southwest side, same tree				Very slight injury to cambium (one piece showed about 10 per cent)
		Northeast side, old seedling tree no. 11				Very slight injury to cambium (less than 1 per cent)
		Southwest side, same tree				No injury to cambium
		Northeast side, young Gano tree no. 15				No injury to cambium
		Southwest side, same tree				No injury to cambium
		Northeast side, young Gano tree no. 16, trunk tarred Oct. 23				No injury to cambium
		Southwest side, same tree				No injury to cambium
12	Nov. 23	Northeast side, young Northern Spy tree no. 18, trunk tarred Oct. 23	7⅙	—23.3°	55	50 per cent injury to cambium
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 17				45 per cent injury to cambium
		Southwest side, same tree				15 per cent injury to cambium
		Northeast side, young Gano tree no. 20				No injury to cambium (except very slight injury to one piece)
		Southwest side, same tree				No injury to cambium
		Northeast side, young Gano tree no. 23, trunk tarred Oct. 23				60 per cent injury to cambium
		Southwest side, same tree				20 per cent injury to cambium
		Young Northern Spy tree no. 22, head, 2½ feet above soil				No injury to cambium
		Same tree, crown, 4 inches above soil				No injury to cambium
13	Dec. 14	West side, old seedling tree no. 1, 4 feet above soil	7⅓	—25.0°	30	Very slight injury to cambium, cortex, and xylem

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
13	(1914) Dec. 14	West side, same tree, 2 feet above soil	7⅓	—25.0°	30	25 per cent injury to cambium, slight to cortex and xylem
		West side, same tree, 4 inches above soil				30 per cent injury to cambium, slight to cortex and xylem
14	Dec. 17	Northeast side, old seedling tree no. 2	Material in freezer placed outside at 6 p. m. Dec. 17. At 9 a.m. Dec. 18, temperature in freezer was —12° C. Freezing continued by means of calcium chlorid and ice 1 hr. 50 min. to —25.5° C.	......	60	5 per cent injury to cambium, slight to cortex and xylem, especially to medullary rays
		Southwest side, same tree				10 per cent injury to cambium, considerable to cortex and xylem, especially to medullary rays
		Northeast side, old seedling tree no. 4, trunk tarred				15 per cent injury to cambium, especially to interfascicular cambium, slight to cortex and xylem
		Southwest side, same tree				10 per cent injury to cambium, especially to interfascicular cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 8, trunk tarred				10 per cent injury to cambium, slight to cortex, considerable to xylem
		Southwest side, same tree				20 per cent injury to cambium, considerable to cortex and xylem
		Northeast side, old seedling tree no. 11				25 per cent injury to cambium, considerable to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 15				35 per cent injury to cambium, especially to interfascicular cambium, considerable to cortex and xylem, especially medullary rays
		Southwest side, same tree				30 per cent injury to cambium, considerable to cortex and xylem, especially medullary rays
		Northeast side, young Gano tree no. 16, trunk tarred				10 per cent injury to cambium and interfascicular cambium, slight to cortex and xylem
		Southwest side, same tree				15 per cent injury to cambium and interfascicular cambium, slight to cortex and xylem *

* Note: Xylem injury unless otherwise noted was to xylem cells.

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
15	(1914) Dec. 18	Northeast side, young Northern Spy tree no. 18, trunk tarred	7⅓	—23.0°	40	70 per cent injury to cambium, severe to cortex, slight to xylem
		Southwest side, same tree				60 per cent injury to cambium, severe to cortex, slight to xylem
		Northeast side, young Northern Spy tree no. 17				25 per cent injury to cambium, severe to cortex, slight to xylem
		Southwest side, same tree				20 per cent injury to cambium, severe to cortex, slight to xylem
		Northeast side, young Gano tree no. 20				50 per cent injury to cambium, severe to cortex, slight to xylem
		Southwest side, same tree				35 per cent injury to cambium, slight to cortex and xylem
		Northeast side, young Gano tree no. 23, trunk tarred				75 per cent injury to cambium, severe to cortex, considerable to xylem
		Southwest side, same tree				80 per cent injury to cambium, considerable to cortex, slight to xylem
		East side, young Northern Spy tree no. 22, 3 feet above soil				80 per cent injury to cambium, severe to cortex, very slight to xylem
		East side, trunk, same tree, 1½ feet above soil				Same
		East side, crown, same tree, 4 inches above soil				65 per cent injury to cambium, severe to cortex, very slight to xylem

Note: Xylem injury in this case was confined to medullary rays, no wood cells injured.

16	(1915) Jan. 13	Old seedling tree no. 1, 4 feet above soil	6⅚	—23.0°	30	Very slight injury to cambium, cortex, and xylem
		Same tree, 2 feet above soil				Same
		Same tree, 6 inches above soil				Very slight injury (about 1 per cent) to cambium, slight to cortex and xylem
		Old seedling tree no. 7, 4 feet above soil				No injury to cambium, slight to cortex and xylem
		Same tree, 6 inches above soil				Very slight injury to cambium, cortex, and xylem
		Old Bellflower tree no. 9, 4 feet above soil				Very slight injury to cambium, slight to cortex, very slight to xylem
		Same tree, 2 feet above soil				Very slight injury to cambium, slight to cortex and xylem (one piece showed 100 per cent cambium injury and severe cortex injury)
		Same tree, 6 inches above soil				Very slight injury (about 1 per cent) to cambium, slight to cortex and xylem

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
17	(1915) Jan. 16	Old seedling tree no. 1, 4 feet above soil	$6\frac{1}{4}$	—26.0°	90	About 2 per cent injury to cambium, slight injury to cortex and xylem
		Same tree, 6 inches above soil				From 1 to 2 per cent injury to cambium, very slight to cortex and xylem
		Old Bellflower tree no. 9, 4 feet above soil				Very slight injury to cambium, cortex, and xylem
		Same tree, 2 feet above soil				Very slight injury (less than 1 per cent) to cambium, very slight to cortex and xylem
		Same tree, 6 inches above soil				From 1 to 2 per cent injury to cambium, very slight to cortex and xylem
		Old seedling tree no. 12, 4 feet above soil				From 2 to 5 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 6 inches above soil				10 per cent injury to cambium, very slight to cortex and xylem

Note: Xylem slightly more injured than cortex.

18	Jan. 20	Northeast side, old seedling tree no. 2	6	—26.5°	30	Very slight injury to cambium, considerable to cortex, slight to xylem
		Southwest side, same tree				Very slight injury to cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 8, trunk tarred				Very slight injury to cambium, considerable to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 11				Very slight injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, considerable to cortex and xylem
		Northeast side, young Gano tree no. 15				Very slight injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, slight to cortex and xylem
		Northeast side, young Gano tree no. 16				Very slight injury to cambium, slight to cortex and xylem
		Southwest side, same tree				Same
19	Jan. 23	Northeast side, young Northern Spy tree no. 18	$7\frac{5}{12}$	—33.0°	40	Very slight injury to cambium, about 5 per cent to interfascicular cambium, slight to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 17				Very slight injury to cambium, mostly to interfascicular cambium, slight to cortex and xylem

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
19	(1915) Jan. 23	Southwest side, same tree	$7\frac{5}{12}$	—33.0°	40	Very slight injury to cambium, about 5 per cent to interfascicular cambium, slight to cortex and xylem
		Northeast side, young Gano tree no. 20				From 1 to 5 per cent injury to cambium, considerable to xylem, less to cortex
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 23, trunk tarred				Very slight injury to cambium, about 5 per cent to interfascicular cambium, slight to cortex and xylem
		Southwest side, same tree				Very slight injury to cambium, considerable to xylem, less to cortex
		Young Northern Spy tree no. 22, trunk, $1\frac{1}{2}$ feet above soil				Very slight injury to cambium, about 10 per cent to interfascicular cambium, considerable to xylem, slight to cortex
		Same tree, head, 3 feet above soil				Same
		Same tree, crown, 4 inches above soil				Very slight injury to cambium, about 5 per cent to interfascicular cambium, slight to cortex and xylem
20	Jan. 27	Young Northern Spy tree no. 35, 2 feet above soil	$6\frac{1}{3}$	—38.0°	40	95 per cent injury to cambium, severe to cortex, less to xylem
		Same tree, 1 inch above soil				From 85 to 90 per cent injury to cambium, severe to cortex and xylem
		Young Northern Spy tree no. 42, head, 3 feet above soil				95 per cent injury to cambium, severe to cortex and xylem
		Same tree, 2 feet above soil				From 95 to 100 per cent injury to cambium, severe to cortex and xylem
		Same tree, 1 inch above soil				95 per cent injury to cambium, severe to cortex and xylem
		Young Northern Spy tree no. 34, at head in crotch				Complete injury to cambium, severe to cortex and xylem
		Same tree, 2 feet above soil				Same
		Same tree, 1 inch above soil				Same
		Young Northern Spy tree no. 30, 2 feet above soil				From 90 to 95 per cent injury to cambium, severe to cortex and xylem
		Same tree, 1 inch above soil				90 per cent injury to cambium, severe to cortex and xylem

Note: Injury greater in extent in cortex than in xylem.

21	Feb. 22	Northeast side, old seedling tree no. 2	6	—38.0°	20	5 per cent injury to cambium, considerable to cortex and xylem

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
21	(1915) Feb. 22	Southwest side, same tree	6	—38.0°	20	10 per cent injury to cambium, considerable to cortex and xylem
		Northeast side, old seedling tree no. 4, trunk tarred				5 per cent injury to cambium, considerable to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 8, trunk tarred				Same
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 11				Same
		Southwest side, same tree				8 per cent injury to cambium, considerable to cortex and xylem
22	Feb. 24	Northeast side, young Gano tree no. 15	6	—37.0°	30	95 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				100 per cent injury to cambium, severe to cortex and xylem
		Northeast side, young Gano tree no. 16, trunk tarred				Same
		Southwest side, same tree				98 per cent injury to cambium, severe to cortex and xylem
		Northeast side, young Northern Spy tree no. 18, trunk tarred				Same
		Northeast side, young Northern Spy tree no. 17				100 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 20				97 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				100 per cent injury to cambium, severe to cortex and xylem
		Northeast side, young Gano tree no. 23, trunk tarred				95 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same

Note: More injury to cortex than to xylem.

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
23	Mar. 4	Northeast side, young Gano tree no. 15	7	—35.0°	30	95 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 16, trunk tarred				85 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 17				75 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				85 per cent injury to cambium, severe to cortex and xylem
		Northeast side, young Gano tree no. 20				90 per cent injury to cambium, severe to cortex and xylem

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
23	(1915) Mar. 4	Southwest side, same tree	7	—35.0°	30	Same
		Northeast side, young Gano tree no. 23				85 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				90 per cent injury to cambium, severe to cortex and xylem
		Northeast side, young Gano tree no. 26, trunk tarred				95 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 27				85 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				90 per cent injury to cambium, severe to cortex and xylem
24	Mar. 6	Northeast side, young Gano tree no. 27, trunk tarred	5½	—32.0°	45	No injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 21				5 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 36, trunk tarred				Same
		Southwest side, same tree				50 per cent injury* to cambium, severe to cortex and xylem
		Northeast side, young Northern Spy tree no. 29				5 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				50 per cent injury* to cambium, severe to cortex and xylem
		Northeast side, young Northern Spy tree no. 30				5 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 32				Same
		Southwest side, same tree				Same
25	Mar. 10	Northeast side, old seedling tree no. 2	5½	—33.0°	30	20 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 4, trunk tarred				5 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				0.5 per cent injury to cambium, severe to cortex and xylem
		Northeast side, old seedling tree no. 8, trunk tarred				2 per cent injury to cambium, considerable to cortex and xylem
		Southwest side, same tree				Very slight injury (less than 1 per cent) to cambium, slight to cortex and xylem

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* This was natural injury to pieces before freezing. More injury to cortex than to xylem.

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
25	(1915) Mar. 10	Northeast side, old seedling tree no. 11	5½	−33.0°	30	20 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old Bellflower tree no. 9				Less than 1 per cent injury to cambium, slight to cortex and xylem
		Southwest side, same tree				2 per cent injury to cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 7				0.5 per cent injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 3				Same
		Southwest side, same tree				Same

Note: Cortex slightly more injured than xylem.

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
25a	Mar. 10	Northeast side, old seedling tree no. 2	5½	−33.0°	30	Trace of injury to cambium, slight to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 4				No injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, cortex, or xylem
		Northeast side, old seedling tree no. 8				No injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, cortex, or xylem
		Northeast side, old seedling tree no. 11				1 per cent injury to cambium, slight to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old Bellflower tree no. 9				5 per cent injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 7				Same
		Southwest side, same tree				Same

Note: In this experiment the pieces of tissue, after being prepared, were soaked for one hour in distilled water, the excess water was blotted off with filter paper, and the pieces were then frozen along with those of lot no. 25.

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
26	Mar. 13	East side, old seedling tree no. 2, 3 feet above soil	4	−23.0°	Removed immediately	3 per cent injury to cambium, slight to cortex and xylem
		Same	4$\frac{1}{12}$	−28.0°	15	5 per cent injury to cambium, slight to cortex and xylem
		Same	4⅓	−33.0°	10	12 per cent injury to cambium, severe to cortex and xylem
27	Mar. 15	East side, young Gano tree no. 20, 2 feet above soil	2½	−25.0°	30	No injury to cambium, slight to cortex and xylem
		Same	2$\frac{7}{12}$	−29.0°	30	Same

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
27	(1915) Mar. 15	Same	$3\frac{1}{12}$	—30.0°	30	Very slight injury (less than 1 per cent) to cambium, slight to cortex and xylem
		South side, young Northern Spy tree no. 28, 2 feet above soil	$2\frac{1}{2}$	—25.0°	30	30 per cent injury to cambium, considerable to cortex and xylem
		Same	$2\frac{7}{12}$	—29.0°	30	Same
		Same	$3\frac{1}{12}$	—30.0°	30	10 per cent injury to cambium, considerable to cortex and xylem
28	Mar. 18	East side, old seedling tree no. 2, 3 feet above soil	Immediate	—20.0°	90	90 per cent injury to cambium, severe to cortex and xylem
		Same	$2\frac{5}{8}$	—28.0°	30	No injury to cambium, slight to cortex and xylem
		Same	$3\frac{1}{6}$ to —30.5°	—31.0°	30 at —30.5° to —31°	Very slight injury to cambium, slight to cortex and xylem except injury to xylem next to cambium layer
29	Mar. 22	East side, old seedling tree no. 2, 2 feet above soil	Immediate	—20.0°	30	From 90 to 95 per cent injury to cambium, considerable to cortex, slight to xylem
		Same	$1\frac{3}{4}$ to —25.0°	—27.0°	30 at —25° to —27°	15 per cent injury to cambium, slight to cortex and xylem
		Same	$1\frac{5}{8}$ to —31.0°	—34.0°	30 at —31° to —34°	From 15 to 20 per cent injury to cambium, considerable to cortex and xylem
30	Mar. 24	East side, old seedling tree no. 2, 3 feet above soil	Immediate	—20.0°	30	80 per cent injury to cambium, considerable to cortex, slight to xylem
		Same	$1\frac{1}{3}$	—30.0°	15 at —30°, 30 at — 29° to —25°	60 per cent injury to cambium, severe to cortex, slight to xylem
		Same	$1\frac{7}{12}$	—32.0°	20	75 per cent injury to cambium, severe to cortex, slight to xylem
31	Mar. 27	Northeast side, old seedling tree no. 2	6	—31.0°	30	No injury to cambium, very slight to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 4, trunk tarred				Same
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 8, trunk tarred				Same
		Southwest side, same tree				Very slight injury (less than 1 per cent) to cambium, very slight to cortex and xylem
		Northeast side, old seedling tree no. 11				0.5 per cent injury to cambium, very slight to cortex and xylem
		Southwest side, same tree				Same

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
31	(1915) Mar. 27	Northeast side, young Gano tree no. 15	6	—31.0°	30	No injury to cambium, very slight to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 16, trunk tarred				Same
		Southwest side, same tree				....
		Northeast side, young Northern Spy tree no. 17				Very slight injury (less than 1 per cent) to cambium, very slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, very slight to cortex and xylem
		Northeast side, young Gano tree no. 20				Same
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 23, trunk tarred				Very slight injury (less than 1 per cent) to cambium, very slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, very slight to cortex and xylem
32	Mar. 31	Northeast side, old seedling tree no. 4, trunk tarred	5½	—33.0°	30	No injury to cambium, very slight to cortex and xylem
		Southwest side, same tree				0.5 per cent injury to cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 8, trunk tarred				Very slight injury (less than 1 per cent) to cambium, very slight to cortex and xylem
		Southwest side, same tree				Same
		Young Northern Spy tree no. 22, 2 feet above soil				Very slight injury (less than 1 per cent) to cambium, slight to cortex and xylem
		Same tree, 4 inches above soil				No injury to cambium, slight to cortex and xylem
		Young Northern Spy tree no. 28, 2 feet above soil				15 per cent injury to cambium, slight to cortex and xylem
		Same tree, 4 inches above soil				Same
		Young Northern Spy tree no. 32, 2 feet above soil				No injury to cambium, slight to cortex and xylem
		Same tree, 4 inches above soil				Same
		East side trunk, old seedling tree no. 2, 3 feet above soil (six pieces)	5¼	—29.0°	30	No injury to cambium, very slight to cortex and xylem
		Same (six pieces)	5½	—33.0°	30	Injury varied in different pieces, from no injury, to from 3 to 5 per cent to cambium, very slight to cortex and xylem
33	Apr. 13	Northeast side, old seedling tree no. 2	6	—30.0°	30	80 per cent injury to cambium, considerable to cortex, slight to xylem
		Southwest side, same tree				Same

TABLE 7 (*concluded*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1915)					
33	Apr. 13	Northeast side, old seedling tree no. 4, trunk tarred	6	—30.0°	30	85 per cent injury to cambium, considerable to cortex, slight to xylem
		Southwest side, same tree				90 per cent injury to cambium, considerable to cortex, slight to xylem
		Northeast side, old seedling tree no. 8, trunk tarred				80 per cent injury to cambium, severe to cortex, less severe to xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 15				95 per cent injury to cambium, severe to cortex, less severe to xylem
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 17				Same
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 23, trunk tarred				85 per cent injury to cambium, severe to cortex, less severe to xylem
		Southwest side, same tree				Same

From a study of the results of artificial freezing, it is apparent that there is no difference in degree of hardiness between the tissue on the southwest and that on the northeast side of the trunk, at least none that can be detected by the method of artificial freezing. It is true that the technique of these experiments is not sufficiently perfect to permit detecting with accuracy any very small differences, but it seems reasonable to believe that any difference so marked as to account for the occurrence of sun-scald on the southwest side of the tree would be easily detected. It is to be noted that in 1915 the freezings were continued later than there was any possibility of the occurrence of sun-scald under natural conditions. The freezings from March 6 to April 13, 1915, show that the trunk tissue was gradually becoming tenderer on both sides; on April 13 it was considerably less hardy than in February, but there was no appreciable difference in the time of this awakening from the dormant condition between the sun-exposed and the shaded side of the trunk. Further, no degree of tenderness was reached on either side great enough to allow the tissue to be killed by temperatures likely to occur in this latitude in March or April.

It seems, in view of this evidence, that Müller-Thurgau's hypothesis to account for the occurrence of sun-scald must be eliminated.

NATURAL INJURY IN THE WINTER OF 1914-15

Some natural injury to the cambium on the southwest side of the trunk was noticed during the winter of 1914-15. This may be reported briefly as follows:

Tree no. 35. Young Northern Spy. Injury to cambium, some to cortex. Injury noticed on January 25, 1915.

Tree no. 18. Young Northern Spy; space on trunk tarred October 23, 1914. On February 24, 1915, a large injured area was found extending from the base of the trunk upward for a distance of one and one-half feet on the southwest side of the tree. The injury was confined to the tarred space. The bark, the cambium, and the outer sapwood were completely killed. The bark was a dead-brown color thruout, but not yet dried out; it seems probable that the injury occurred sometime in the winter of 1914-15. Cuttings for artificial freezing had been taken from this tree at intervals all winter, but from a point a few inches above the upper limit of this injury. The injured tissue was accidentally cut into on February 24 and the injury discovered. It was not yet apparent externally.

Tree no. 26. Young Gano; space on trunk tarred October 23, 1914. Partial injury to cambium, slight injury to cortex, very slight injury to xylem, observed on February 24, 1915. This injury could be detected only by aid of the microscope. Cuttings from this tree had been previously examined at intervals, but only macroscopically.

Tree no. 25. Young Gano; space on trunk tarred November 23, 1914. Injury as described in preceding paragraph, observed on February 24, 1915. No previous examination.

Tree no. 28. Young Northern Spy. Same injury as described above observed on February 24, 1915. No previous examination.

Tree no. 43. Young Northern Spy. Same injury as described above observed on February 24, 1915. No previous examination.

Tree no. 36. Young Northern Spy; space on trunk tarred January 15, 1915. Injury 50 per cent to cambium, some injury to cortex and xylem; could be detected only microscopically; observed on March 8, 1915. Cuttings from this tree had been examined previously at intervals, but only macroscopically.

Tree no. 29. Young Northern Spy. Injury 50 per cent to cambium, some injury to cortex and xylem, observed under microscope on March 8, 1915. No previous examination.

Altho these observations are not conclusive as to the date of occurrence of the injury, yet, taken in connection with the artificial freezing work, they are interesting as showing that natural injury occurred in 1915 before there was any possibility for the tissue on the southwest side of the tree to become tenderer.

There now remains one hypothesis to account for the occurrence of sun-scald. That is, that it may result from a rapid temperature fall consequent to the warming-up of the tissue on a cold, sunny day.

With proper conditions this point might be determined in the following manner: On a day when the tissue on the southwest side of the tree had been thoroly thawed out while that on the northeast side had remained very cold, say about −16° C., if a fairly rapid fall of temperature occurred after sundown, conditions would be proper for sun-scald provided a certain minimum temperature were reached. It seems probable that by taking tissue from opposite sides of the tree in the early morning, while it was yet at the minimum temperature for the night and without allowing it to warm up, and carrying several samples of the tissue down to different minima by the use of freezing mixture, a point might be reached at which the tissue from the southwest side would kill while that from the northeast side would not.

Such conditions are rare, and it was not possible to run this experiment during the winters of 1913-14 and 1914-15. It is believed that if the experiment could be performed it would offer conclusive evidence with regard to the hypothesis under consideration.

In the absence of such evidence something may be learned from a comparison of the effects of rapid and slow freezing. Chandler (1913), in determining the comparative effect of rapid and slow freezing, employed the winter twigs and buds of various fruit trees. It seemed worth while to run a few freezings in order to determine whether the same phenomena were apparent in the case of the tissues under discussion here — the cambium, the xylem, and the cortex from the trunk of apple trees in the winter condition.

Among the freezing experiments recorded in table 7 are some that have a bearing on this point, and of these a few deserve review here:

(a) Tissue frozen on January 28, 1914, three and one-fourth hours to −20.6° C., one-half hour at minimum, killed more severely than similar tissue (not, however, from the same tree) frozen on January 30, seven hours to −20.6° C., one-half hour at minimum.

(b) March 19, 1914, pieces of tissue from the same trees were frozen seven hours to −28° C., one hour at minimum; two and one-half hours to −18.3° C., one-half hour at minimum; severe cambium injury in both cases.

(c) March 15, 1915, tissue from a young Gano tree, no. 20, was frozen two and one-half hours to −25° C., one-half hour at minimum, with no injury to cambium; two hours and thirty-five minutes to −29° C., one-half hour at minimum, with no injury to cambium; three hours and five minutes to −30° C., one-half hour at minimum, with very slight injury to cambium and slight injury to cortex and xylem.

March 27, 1915, tissue from the same tree was frozen six hours to −31° C., one-half hour at minimum, with no injury to cambium and very slight injury to cortex and xylem.

(d) March 15, 1915, tissue from a young Northern Spy tree, no. 28, was frozen two and one-half hours to −25° C., one-half hour at minimum, with 30 per cent injury to cambium and considerable injury to cortex and xylem; two hours and thirty-five minutes to −29° C., one-half hour at minimum, with 30 per cent injury to cambium and considerable injury to cortex and xylem; three hours and five minutes to −30° C., one-half hour at minimum, with 10 per cent injury to cambium and considerable injury to cortex and xylem.

March 31, 1915, tissue from the same tree was frozen five and one-half hours to −33° C., one-half hour at minimum, with 15 per cent injury to cambium and slight injury to cortex and xylem.

(e) March 18, 1915, tissue from an old seedling tree, no. 2, was frozen immediately to −20° C., one and one-half hours at minimum, with 90 per cent injury to cambium and severe injury to cortex and xylem; two hours and fifty minutes to −28° C., one-half hour at minimum, with no injury to cambium and slight injury to cortex and xylem; three hours and ten minutes to −30.5° C., one-half hour at minimum, with very slight injury to cambium and slight injury to cortex and xylem.

March 22, 1915, tissue from the same tree was frozen immediately to −20° C., one-half hour at minimum, with from 90 to 95 per cent injury to cambium, considerable injury to cortex, and slight injury to xylem; one hour and forty-five minutes to −25° C., one-half hour at minimum, with 15 per cent injury to cambium and slight injury to cortex and xylem; one hour and fifty minutes to −31° C., one-half hour at minimum, with from 15 to 20 per cent injury to cambium and considerable injury to cortex and xylem.

March 24, 1915, tissue from the same tree was frozen immediately to −20° C., one-half hour at minimum, with 80 per cent injury to cambium, considerable injury to cortex, and slight injury to xylem; one hour and twenty minutes to −30° C., three-fourths hour at minimum, with 60 per cent injury to cambium, severe injury to cortex, and slight injury to xylem; one hour and thirty-five minutes to −32° C., twenty minutes at minimum, with 75 per cent injury to cambium, severe injury to cortex, and slight injury to xylem.

March 27, 1915, tissue from the same tree was frozen six hours to −31° C., one-half hour at minimum, with no injury to cambium and very slight injury to cortex and xylem.

March 31, 1915, tissue from the same tree was frozen five and one-fourth hours to −29° C., one-half hour at minimum, with no injury to cambium and very slight injury to cortex and xylem; five and one-half hours to −33° C., one-half hour at minimum, with very slight injury to cambium, cortex, and xylem.

In addition to the experiments described above, it may be stated that at several times during the winter, when there has been occasion to kill tissue by artificial freezing, it has always been possible to accomplish this by immediate freezing to −20° C. Also, at different times during the dormant period two-years-old apple and pear trees have been subjected to this immediate freezing by placing galvanized iron cylinders around the trunks and packing the space within with salt-and-ice mixture. In these experiments severe killing resulted in bark, cambium, and outer sapwood.

In considering these results the temperature observations of February 14, 1916, should be recalled. It will be seen by referring to table 5 (page 255) that the temperature of the tissue on the southwest side of the small tree trunk fell from −0.3° C. to −14.4° C. in one hour, in the critical part of the freezing period. While not warranting a definite conclusion, this indicates that a rate of temperature fall may occur in nature rapid enough to raise the killing point of the tissue, and suggests the probability that sun-scald may result from this condition.

RELATIVE HARDINESS OF TISSUE FROM THE CROWN AND THE UPPER PARTS OF THE TRUNK

Chandler (1913), as the result of a number of artificial freezings, concludes that the tissue at the crown, or base, of the tree becomes hardy more slowly at the beginning of the winter than does tissue from the higher parts of the tree. In the freezings reported in table 7, tissue for preliminary freezings was taken from various heights on the trunk, with the idea that this difference in hardiness would make it easier to approximate the killing point. In the earlier freezings this difference was marked, but it did not appear in the freezings of December 18 and January 19.

A few freezings were then run in order to test this point more fully, and it seemed, at least in the year 1914-15, that this greater tenderness of the tissue at the base of the trunk had disappeared by midwinter (table 7, lots 10, 13, 15, 16, 17, 19, and 20). The results of these freezings would indicate that crown injury is normally an early-winter injury. In this connection it is interesting to recall Selby's mention (referred to on page 243) of crown injury in Ohio which he believes was caused by the October freeze of 1906. Clinton (1904) describes crown injury which he believes occurred on December 9, 1903. Reddick (1912) cites weather records showing that crown injury prevalent thruout New York in the spring of 1911 and noticeable early in January probably occurred in either November or December of 1910. Chandler, however, found this difference in hardiness evident as late as March 25, in the winter of 1912-13.

A more thoro test of this point was made during the winter of 1915-16 at Geneva, New York. Tissue for these freezings was taken from a number of thirty-years-old Baldwin trees in the experiment station orchard. The results of these freezings are given in table 8. It will be seen that in these trees and in this season the difference in hardiness between the crown and the upper trunk was still evident at the end of March. Since, however, the crown tissue was noticeably hardier than it was in November, it is still entirely possible that crown injury occurs oftener in the early winter than later.

TABLE 8. RECORD OF ARTIFICIAL FREEZING EXPERIMENTS TO DETERMINE RELATIVE HARDINESS OF TISSUE OF THE TRUNKS OF TREES

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
1	(1915) Nov. 10	Tree no. 51, crown, 1 inch above soil	5¾	—20.0°	15	25 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3½ feet above soil				No injury to cambium, slight to cortex and xylem
		Tree no. 52, crown, 1 inch above soil				2 per cent injury to cambium, slight to cortex, considerable to inner xylem
		Same tree, 2 feet above soil				No injury to cambium, very slight to cortex and xylem
		Same tree, 3½ feet above soil				No injury to cambium, very slight to cortex, none to xylem
		Tree no. 53, crown, 1 inch above soil				50 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, cortex, or xylem
		Tree no. 54, crown, 1 inch above soil				No injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3½ feet above soil				No injury to cambium, very slight to cortex and xylem
2	Nov. 17	Tree no. 55, crown, 1 inch above soil	5¾	—22.0°	30	0.5 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3 feet above soil				No injury to cambium, slight to cortex, very slight to xylem
		Tree no. 53, crown, 1 inch above soil				10 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3 feet above soil				15 per cent injury to cambium, considerable to cortex, slight to xylem
		Tree no. 56, crown, 1 inch above soil				No injury to cambium, very slight to cortex and xylem
		Same tree, 3½ feet above soil				Same
		Tree no. 57, crown, 1 inch above soil				Same
		Same tree, 2 feet above soil				Same
		Same tree, 3½ feet above soil				Same
		Tree no. 54, crown, 1 inch above soil				Same
		Same tree, 3 feet above soil				Same
3	Nov. 23	Tree no. 54, crown, 1 inch above soil	6½	—25.0°	30	15 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 2½ feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 56, crown, 1 inch above soil				Same
		Same tree, 2½ feet above soil				Same

TABLE 8 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
3	(1915) Nov. 23	Tree no. 57, crown, 1 inch above soil	6½	—25.0°	30	75 per cent injury to cambium, considerable to cortex, slight to xylem
		Same tree, 3½ feet above soil				Same
		Tree no. 58, crown, 1 inch above soil				80 per cent injury to cambium, slight to cortex and xylem
		Same tree, 3½ feet above soil				85 per cent injury to cambium, slight to cortex and xylem
4	Dec. 3	Tree no. 60, crown, 1 inch above soil	6⅚	—27.0°	25	10 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3½ feet above soil				No injury to cambium, slight to cortex, very slight to xylem
		Tree no. 56, crown, 1 inch above soil				15 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3½ feet above soil				2 per cent injury to cambium, very slight to cortex and xylem
		Tree no. 57, crown, 1 inch above soil				50 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3½ feet above soil				30 per cent injury to cambium, slight to cortex, very slight to xylem
		Tree no. 58, crown, 1 inch above soil				50 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3½ feet above soil				Same
5	(1916) Jan. 21	Tree no. 51, crown, 1 inch above soil	6½	—28.0°	30	Severe injury to cambium, slight to cortex and xylem
		Same tree, 3½ feet above soil				2 per cent injury to cambium, slight to cortex and xylem
		Tree no. 52, crown, 1 inch above soil				Same
		Same tree, 3½ feet above soil				No injury to cambium, slight to cortex, very slight to xylem
		Tree no. 56, crown, 1 inch above soil				Same
		Same tree, 3 feet above soil				Same
		Tree no. 58, crown, 1 inch above soil				25 per cent injury to cambium, considerable to cortex, slight to xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 54, crown, 1 inch above soil				Trace of injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 55, crown, 1 inch above soil				Trace of injury to cambium, very slight to cortex and xylem

TABLE 8 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
5	(1916) Jan. 21	Same tree, 3 feet above soil	6½	—28.0°	30	Same
		Tree no. 53, crown, 1 inch above soil				Trace of injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3 feet above soil				Same
6	Jan. 27	Tree no. 51, crown, 1 inch above soil	6¾	—30.0°	15	75 per cent injury to cambium, considerable to cortex and xylem
		Same tree, 3 feet above soil				2 per cent injury to cambium, very slight to cortex and xylem
		Tree no. 52, crown, 1 inch above soil				Same
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Same tree, 6 inches below soil				35 per cent injury to cambium, slight to cortex and xylem
		Tree no. 54, crown, 1 inch above soil				No injury to cambium, slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Same tree, 4 inches below soil				75 per cent injury to cambium, considerable to cortex and xylem
		Tree no. 56, crown, 1 inch above soil				45 per cent injury to cambium, considerable to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 57, crown, 1 inch above soil				25 per cent injury to cambium, slight to cortex and xylem
		Same tree, 3 feet above soil				2 per cent injury to cambium, slight to cortex and xylem
		Tree no. 58, crown, 1 inch above soil				5 per cent injury to cambium, slight to cortex and xylem
		Same tree, 3 feet above soil				Same
6a	Jan. 27	Tree no. 51, crown, 1 inch above soil	6¾	—30.0°	15	75 per cent injury to cambium, considerable to cortex and xylem
		Same tree, 3 feet above soil				5 per cent injury to cambium, slight to cortex and xylem
		Tree no. 52, crown, 1 inch above soil				25 per cent injury to cambium, considerable to cortex, slight to xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Same tree, 6 inches below soil				90 per cent injury to cambium, considerable to cortex, slight to xylem
		Tree no. 54, crown, 1 inch above soil				No injury to cambium, very slight to cortex and xylem

TABLE 8 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
6a	(1916) Jan. 27	Same tree, 3 feet above soil	6¾	—30.0°	15	Same
		Tree no. 56, crown, 1 inch above soil				50 per cent injury to cambium, considerable to cortex, slight to xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 57, 3 feet above soil				From 2 to 5 per cent injury to cambium, very slight to cortex and xylem
		Tree no. 58, 3 feet above soil				75 per cent injury to cambium, considerable to cortex, slight to xylem
7	Mar. 22	Tree no. 51, base	6¾	—31.0°	15	25 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 52, base				30 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 53, base				25 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 54, base				Same
		Same tree, 3 feet above soil				Same
		Tree no. 56, base				Same
		Same tree, 3 feet above soil				Same
		Tree no. 57, base				From 2 to 5 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
8	Mar. 29	Tree no. 54, base	7 (6 hours 0 to —12°, 1 hour —12° to —32°)	—32.0°	15	40 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				20 per cent injury to cambium, very slight to cortex and xylem
		Tree no. 56, base				10 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 57, base				10 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem

Note: In this experiment the pieces of tissue were soaked in distilled water for one-half hour before freezing. The excess water was poured off and the pieces were frozen while wet, along with those of lot no. 6.

TABLE 8 (*concluded*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
8	(1916) Mar. 29	Tree no. 58, base	7 (6 hours 0 to —12°, 1 hour —12° to —32°)	—32.0°	15	10 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 62, base				No injury
		Same tree, 3 feet above soil				No injury
		Tree no. 51, northeast side of trunk				No injury
		Same tree, southwest side				No injury
		Tree no. 52, northeast side of trunk				Very slight injury to cambium (from 1 to 5 per cent), very slight to cortex and xylem. No difference between opposite sides of trunk
		Same tree, southwest side				Same
		Tree no. 61, northeast side of trunk				Same
		Same tree, southwest side				Same
		Tree no. 62, northeast side of trunk				Same
		Same tree, southwest side				Same
		Tree no. 55, northeast side of trunk				5 per cent injury to cambium, very slight to cortex and xylem
		Same tree, southwest side				No injury to cambium, very slight to cortex and xylem

EFFECT OF FREEZING TISSUE WHEN WET

Macoun's (1908) explanation of crotch injury suggests that a wet or water-soaked condition of the tissue previous to freezing may increase the killing.

A comparison of the experiments reported in table 7, lots 25 and 25a, and table 8, lots 6 and 6a, shows that soaking the tissue in distilled water and freezing it while wet did not increase the amount of killing.

CONCLUSION

Sun-scald, an injury sometimes occurring to bark, cambium, and outer sapwood on the southwest side of tree trunks, particularly of apple trees, is probably a winter injury caused by direct freezing to death of the tissue. This freezing to death is, it is believed, made possible by a rapid temperature fall consequent to warming-up of the tissue above freezing by the rays of the sun on a bright, cold day in late winter.

Sun-scald seems to be a late-winter injury, as distinguished from crown rot, which is perhaps an early-winter injury; sun-scald is therefore not induced by late growth or an unripened condition of the trees in the fall, while crown rot no doubt is. An important factor in the cause of crown rot is the lower degree of hardiness of the tissue at the base of the trunk than on the upper parts.

A practical method of preventing sun-scald is to spray or paint the trunks with whitewash in fall or early winter. This is not a new recommendation, since it has been suggested by Müller-Thurgau, in 1886, and by various other writers since that time. It seems, however, that it is a more feasible method than other recommendations that have been made, such as shading the trunk with a board or with brush. It seems worthy of a trial, especially in northern regions where sun-scald is a not uncommon type of winter injury. Of course this injury is one that occurs only in certain years, usually with a considerable intermediate period of immunity, so that it is not probable that this method will ever come into wide use. It would obviously be employed many times unnecessarily for once when it was necessary.

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THE PINE BARK BEETLE

WILBERT A. CLEMENS

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THE PINE BARK BEETLE

(*Ips pini* Say)

Order, *Coleoptera* Family, *Ipidae*

WILBERT A. CLEMENS

The pine bark beetle, *Ips pini* Say, first attracted the attention and interest of the writer in the summer of 1912, in the Georgian Bay region at Go-Home Bay, where various stages of the insect were to be found in practically every recently fallen white pine tree. Early in the season of 1913 several badly infested logs were found in the vicinity of Ithaca, New York, and at that time the writer began a study of this beetle for the purpose of obtaining details of its life history and habits. The investigations extended over a period of three years, during which time many infested pines have been examined and the habits and stages of the insect observed in considerable detail. In this bulletin an attempt is made to present these details as they have been found during this period of study.

HISTORICAL

The pine bark beetle was first described by Thomas Say (1827).[1] Many years later Fitch (1858) gave a brief description of the galleries made by it in the bark of pine. Still later Packard (1890) briefly described the beetle and its galleries. Hopkins (1893 a: 139) found the beetle very abundant in West Virginia. He named the trees attacked by it in that State, listed its enemies, and presented definite data regarding the times of the year at which he found adults, larvæ, and eggs. He subsequently (1899) made numerous references to the beetle and gave additional data concerning it.

Felt (1906) gives the most extended discussion of the insect that the writer has found. He describes the adult, gives a brief account of its life history and habits, discusses its distribution and the amount of injury it causes in New York State, and offers suggestions concerning methods of control. The article is accompanied by good illustrations.

SYNONYMY

The pine bark beetle belongs to the order Coleoptera, suborder Rhyncophora, family Ipidae, subfamily Ipinae (Swaine, 1909). The genus was formerly known as *Tomicus*, but the synonymy according to Swaine (page 77 of reference cited) gives the name *Ips* De Geer (1775) priority. The species *pini* was described by Say (1827).

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[1] Dates in parenthesis refer to literature cited, page 298.

The following synonymy is that given by Swaine (page 125 of reference cited):

pini Say

1826 Bostrichus. Say. Acad. Nat. Sci. Phila. Jour. 5:257; ed. Lec. 2:319
1837 Tomicus. Kirby. Faun. Bor. Am. 4:191
1841 Tomicus. Harris. Ins. N. E. p. 74
1852 Tomicus. Harris. Rep't Ins. Inj. Veg. p. 78
1858 Tomicus. Fitch. Nox. Ins. N. Y. 4th Rep't, p. 722, 751
1868 Bostrichus. Zimmerman. Am. Ent. Soc. Trans. 2:147
1868 Tomicus. Leconte. Am. Ent. Soc. Trans. 2:163
1876 Tomicus. Leconte. Am. Phil. Soc. Proc. 15:363, 365
1877 Tomicus. Provancher. Faun. Ent. Can. 1:570
1878 Tomicus. Hubbard & Schwarz. Am. Phil. Soc. Proc. 17:666
1888 Tomicus. Schwarz. Ent. Soc. Wash. Proc. 1:80, 149, 175
1890 Tomicus. Packard. U. S. Ent. Com'n, 5th Rep't, p. 713–14, 858, fig. 247
1893 Tomicus. Hopkins. W. Va. Agric. Exp. Sta. Bul. 31, p. 139; Bul. 32, p. 212
1894 Tomicus. Hopkins. Can. Ent. 26:280
1899 Tomicus. Hopkins. W. Va. Agric. Exp. Sta. Bul. 56, p. 342, 343, 422, 445
1899 Tomicus. Hopkins. U. S. Div. Ent. Bul. 21, p. 16
1900 Ips. Smith. Cat. Ins. N. J. p. 363
1901 Tomicus. Felt. N. Y. Forest, Fish & Game Com'n Rep't, 7:487–88, fig. 7
1903 Tomicus. Gillette. Col. Agric. Rep't, 24:117
1906 Tomicus. Felt. N. Y. State Mus. Mem. 8, 2:334, 338, 351–54, 359, 376, fig. 70, 71

dendatus Sturm.

1826 Tomicus. Sturm. Cat. p. 76, t. 4, fig. 30
1876 =pini Say. Leconte. Am. Phil. Soc. Proc. 15:426

pallipes Sturm.

1826 Tomicus. Sturm. Cat. p. 76
1876 =pini Say. Leconte. Am. Phil. Soc. Proc. 15:426

praefrictus Eich.

1867 Tomicus. Eichhoff. Berl. Ent. Zeit. p. 401
1876 =pini Say. Leconte. Am. Phil. Soc. Proc. 15:365

DESCRIPTIONS

The adult

The following is the description of the adult (Plate XX, 2 and 3) as given by Say (1827):

> Dark chesnut; elytra excavated at tip, each about four toothed.
>
> *Body* somewhat hairy, chesnut brown: *head* with minute elevated points: *antennæ* pale rufous: *thorax* punctured, more particularly hairy before, and on each side; before the middle, with numerous small elevated points, more acute towards the anterior margin: *elytra* more particularly hairy each side, with striæ of transverse punctures; interstitial lines impunctured; tip truncated obliquely, and excavated; the exterior edge on each side, with four denticulations, of which the second from above is the largest, and the inferior one is smallest, and most acute; there are sometimes two very small ones above, near the suture.
>
> Length 3/20 of an inch.
>
> This species is very closely allied to *B. exesus*. It is very destructive to many species of pine. Mr. Z. Collins informs me that it depredates on the larch, (*Pinus pendula*, ? Aiton.) Dr. J. Mease recently exhibited to me some sections of limbs of the silver-pine (*Pinus strobus*) trees, which decorate the public squares of this city, now discovered to be seriously injured by the attacks of this insect.

The characters that distinguish this beetle from all other species of Ips are, (1) the four teeth along the margin of the excavation of each elytrum (fig. 62), and (2) the size, the beetles being about 4 millimeters long. Dr. Felt has figured the teeth, the tibiæ, the antennæ, and the proventriculus.

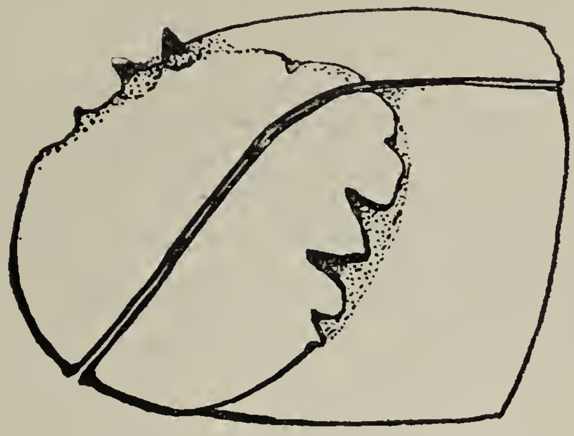


FIG. 62. ARRANGEMENT OF TEETH ALONG MARGIN OF EXCAVATION OF DISTAL ENDS OF ELYTRA. ENLARGED

It is rather difficult to distinguish the sexes by external characters. The only characters that appear to hold at all are: (1) the difference in size of the individuals, the females being slightly larger as a rule than the males; and (2) the size of the teeth along the excavation of the elytra, and even this does not hold in all cases. As a rule, the second and third teeth — that is, the two middle ones of the elytrum — are considerably longer and stouter in the male than in the female. It has been found that by using these characters the sexes can be distinguished with almost entire accuracy. The ultimate distinction, of course, is in the internal reproductive organs. These are shown in figures 63 and 64.

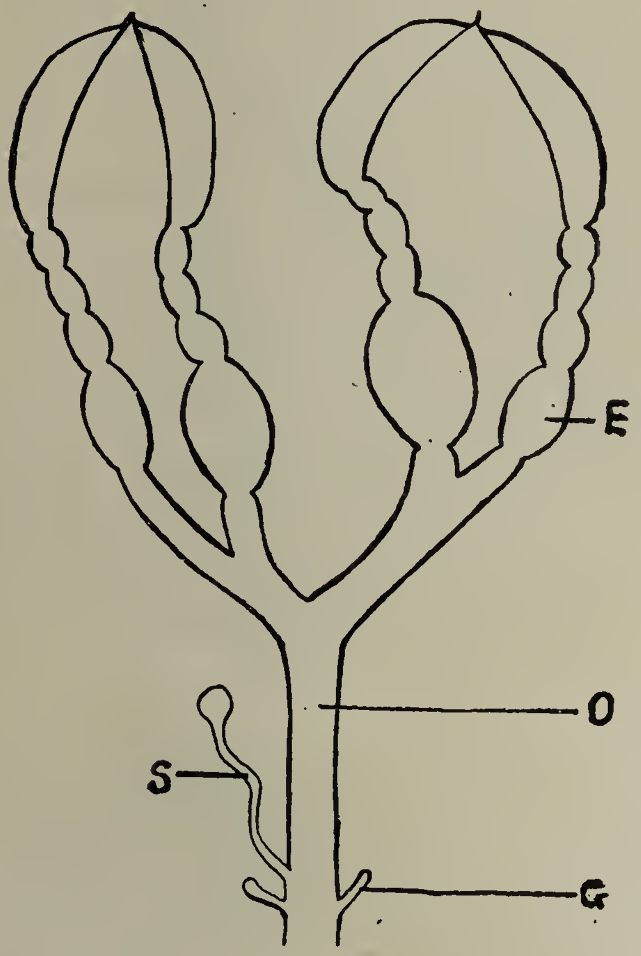


FIG. 63. REPRODUCTIVE ORGANS OF FEMALE

E, Egg tube; O, oviduct; S, receptaculum seminis; G, gland. Enlarged

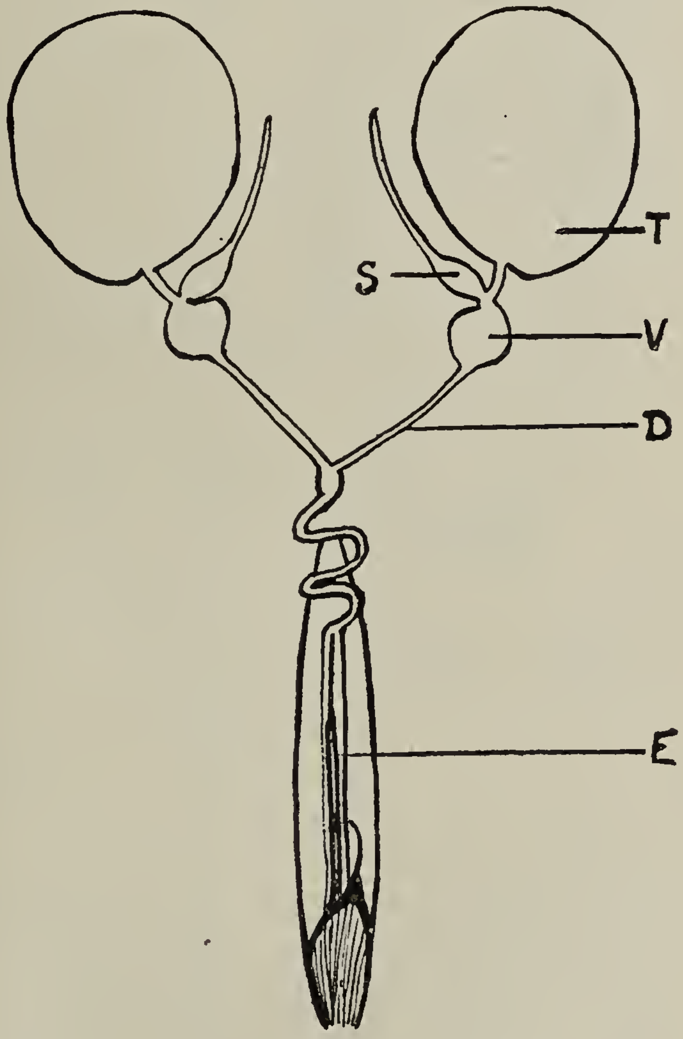


FIG. 64. REPRODUCTIVE ORGANS OF MALE

T, Testis; S, gland; V, seminal vesicle; D, vas deferens; E, ejaculatory apparatus. Enlarged

The egg

The egg is elliptical in shape and about 0.75 millimeter long. It has a smooth, glistening surface and is a beautiful pure white in color.

The larva

The larva when it hatches is a small grub 1 millimeter in length (Plate XX, 1). The mature larva reaches a length of 4 millimeters. The body is a pure glistening white, often tinged with reddish brown due to the food material in the alimentary canal. The head is strongly chitinized and is light brown in color. The body is arcuate, wrinkled, and covered with scattered white hairs. The thoracic segments are larger than the segments of the abdomen. The ventral surface of the thorax is flat, and shows knob-like enlargements laterally in the positions of the legs. The mouth parts consist of labium, maxillæ, and mandibles.

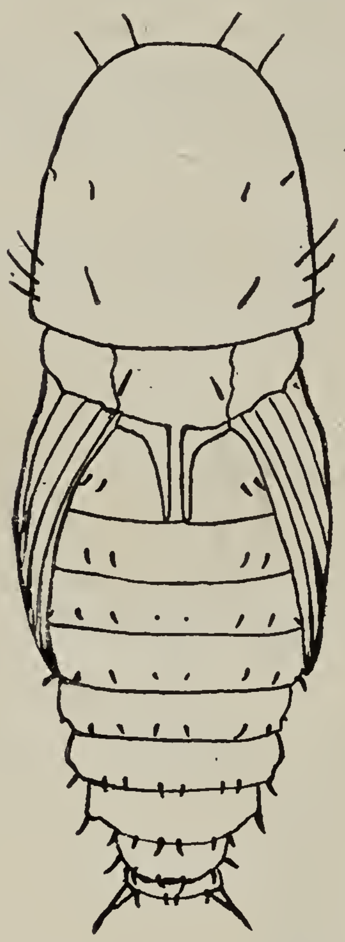


FIG. 65. PUPA, DORSAL VIEW. ENLARGED

The pupa

The pupa (fig. 65) is slightly over 3 millimeters in length and is pure white in color. The head is bent forward. The wings, shorter than the body, are turned beneath the body so that the tips meet ventrally and thus the dorsal surface of the abdomen is exposed. The abdomen ends in a pair of divaricate spines. The body is covered with small yellow bristles — six on the head, four prominent ones along the anterior margin of the prothorax, four more just posterior to these and eight along the posterior margin, two pairs on the dorsal surface of both meso- and meta-thorax, and eight along the posterior margin of each abdominal segment.

DISTRIBUTION

This species is common and widely distributed. Apparently it was first known in the vicinity of Philadelphia, but it has since been reported in twelve States — namely, Washington, Oregon, Idaho, Colorado, Michigan, West Virginia, Maryland, Maine, Pennsylvania, New York, New Jersey, and Massachusetts — and in two provinces of Canada, namely, Ontario and Quebec. The species thus inhabits the transitional and Canadian faunal zones ranging from the Pacific to the Atlantic and from about 37° to 55° north latitude. The distribution is shown in the table on the opposite page:

Distribution of Ips pini Say

Locality	State or province	Date	Collector or authority	Host	Reference
Philadelphia	Pennsylvania	1826	Say	Many species of pine	Acad. Nat. Sci. Phil. Journ. **5**:257
New York to Cumberland-house		1837	Kirby		Fauna Bor. Amer. **4**:191
	Massachusetts	1841	Harris		Ins. Mass., p. 74
New England		1842	Harris	Larch, white pine, pitch pine	Ins. N. E., p. 74
	New York	1858	Fitch	Pine, larch	Ins. N. Y., 4th Rept., p. 722, 751
Atlantic States, Canada, Oregon		1868	Le Conte		Amer. Ent. Soc. Trans. **2**:163
Northern and western parts of Atlantic district		1876	Le Conte		Amer. Ent. Soc. Proc. **15**:365
From Canada to Hudson Bay Territory	Quebec	1877	Provancher		Fauna Ent. Can. **1**:570
Port Huron (Lower peninsula of Michigan)	Michigan	1878	Hubbard and Schwarz		Amer. Phil. Soc. Proc. **17**:666
Marquette (Lake Superior region)	Michigan	1878	Hubbard and Schwarz		Amer. Phil. Soc. Proc. **17**:643
Vicinity of Washington, D. C.		1888	Schwarz	Pinus inops	Ent. Soc. Wash. Proc. **1**:80
	Maine	1890	Packard	Pine woods	U. S. Ent. Comm., 5th Rept., p. 714
Rocky Mountains of Colorado		1890	Packard	Abies menziesii	U. S. Ent. Comm., 5th Rept., p. 714
Rist Canon	Colorado	1891	Gillette		Colo. State Bd. Agr. Rep't. **24**:117
Six counties of West Virginia		1893	Hopkins	All pines, norway spruce, black spruce	W. Va. Agr. Exp. Sta. Bul. 31:139; Bul. 32:212
Spokane	Washington	1899	Hopkins	Lodgepole pine	U. S. Div. Ent. Bul. 21, p. 16
Moscow	Idaho	1899	Hopkins	Yellow pine	U. S. Div. Ent. Bul. 21, p. 16
Newark and other places	New Jersey	1900	Smith	Pine, spruce	Ins. N. J., p. 363
Trenton	Ontario	1904	Evans		Ent. Soc. Ont., 35th Ann. Rept., p. 85
Widely distributed	New York	1906	Felt	White pine, tamarack	N. Y. State Mus. Mem. 8:2:351–352
Ithaca	New York	1906	Swaine		Thesis, Cornell Univ.
Georgian Bay	Ontario	1912	Clemens	White pine	
Ithaca	New York	1913–15	Clemens	White pine, pitch pine	

HOSTS

Dr. Hopkins reports that in the State of West Virginia all species of pine are attacked by *Ips pini*, as well as black spruce and norway spruce. He reports also that in Washington the beetle was found in lodgepole pine and in Idaho in yellow pine. Harris and Fitch report it as attacking larch, and Packard as attacking *Abies menziesii* in Colorado. In the vicinity of Ithaca it has been found only in white pine and pitch pine. It is probable, therefore, that this beetle attacks all species of pine in the Canadian and transitional zones, as well as black spruce, norway spruce, *Abies menziesii*, and larch.

LIFE HISTORY

Hibernation

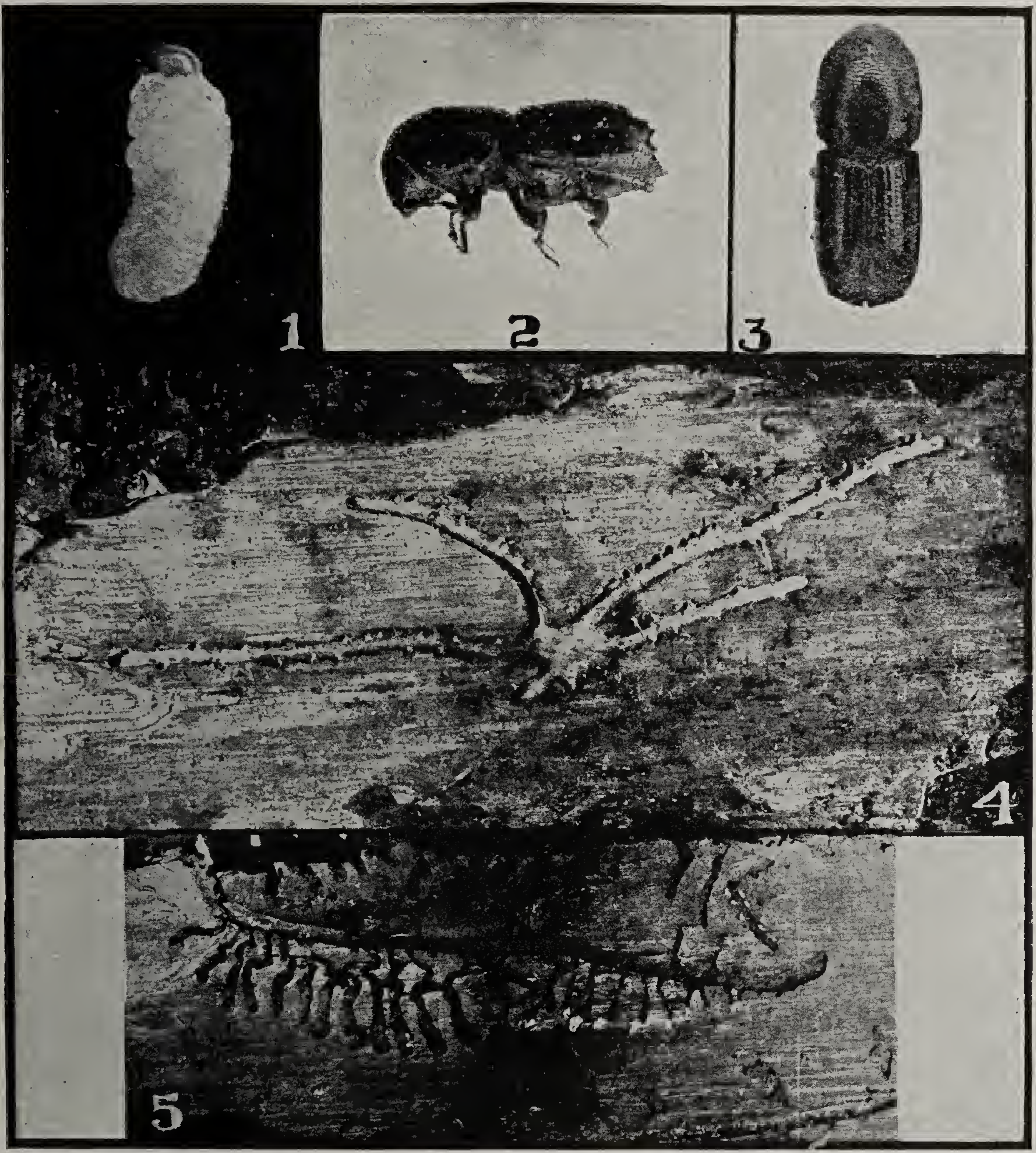
The insect usually passes the winter in the adult stage. In the vicinity of Ithaca it has been found in hibernation as adult only, but Dr. Hopkins reports that bark beetles, apparently of many species, winter in the larval and pupal stages as well. The larvæ of *Ips caelatus* Eich. have been found in hibernation, and so it should not be impossible for *Ips pini* to winter in the immature stage in this region.

The beetles hibernate in the bark. Usually no trace of the cambium remains at the end of the season, and the space between the wood and the bark is filled with chips, sawdust, and excreta of larvæ and adults of the bark beetles, and of larvæ of cerambycid, buprestid, and other beetles. Tunnels are bored in the bark, and in spring the beetles make their exit through round holes 1.5 millimeters in diameter (Plate XXI, 3).

Migration takes place early in spring after the first few warm days. On May 9, 1914, a number of beetles were found just beginning to enter the bark of a fallen white pine. Again on April 30, 1915, a log was found in which the beetles had finished the nuptial chambers and the females had just commenced the galleries. This infestation probably began on April 27 or 28. The maximum air temperature during the week of May 2 to 9, 1914, averaged 70° F., while the week previous it averaged 57° F. In 1915 during the week of April 23 to 30 the average maximum air temperature was 82° F., while the week previous it was 62° F. Thus there appears to be a distinct relationship between the temperature and the time of emergence of the beetles from hibernation.

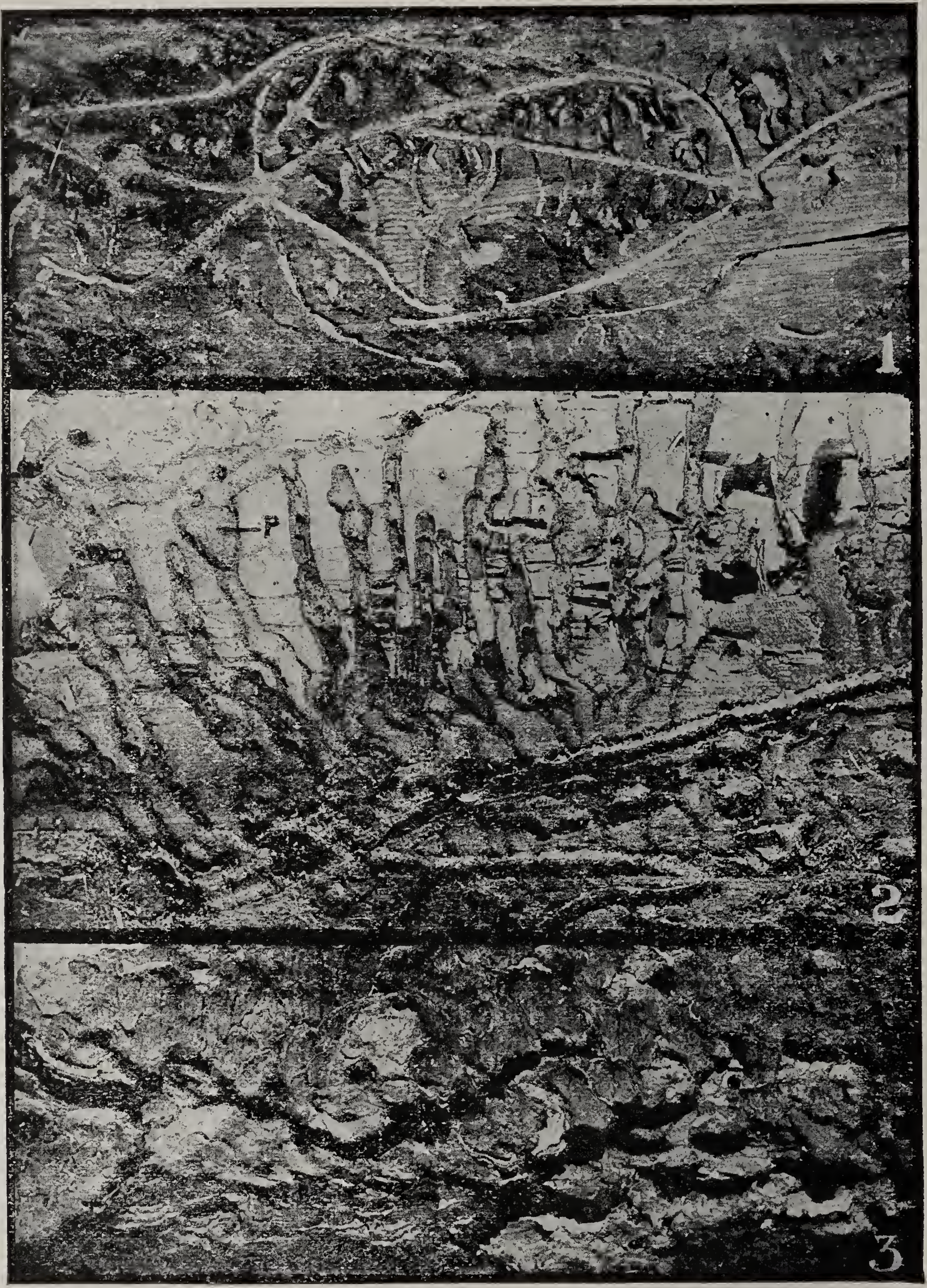
Attack

The beetles have never been observed to leave a tree nor observed in flight. Dr. Hopkins reports swarms of bark beetles in West Virginia on April 30 and May 4, 1893, but no mention is made of *Ips pini* although *Ips cacographus* is recorded.



IPS PINI SAY AND ITS WORK

1, Larva. Enlarged
2, Adult, lateral view. Enlarged
3, Adult, dorsal view. Enlarged
4, White pine log with bark removed, showing nuptial chamber, primary galleries, and egg niches
5, Primary gallery, with secondary, or larval, galleries in early stages



WORK OF IPS PINI SAY

1, Work of *Ips pini* on the wood beneath the bark of a white pine log
2, Work of *Ips pini* on the inner surface of white pine bark. P, a pupal chamber, with an exit hole just above
3, Entrance and exit holes on outer surface of white pine bark

Just how the beetles find new feeding and breeding grounds is not known, but possibly they are attracted by the resinous odor of an injured tree. The odor of a newly fallen pine is discernible to a person for a considerable distance, and it is not inconceivable that bark beetles can detect this odor at much greater distances. On June 1, 1915, a white pine log which had fallen in April was sawed up and placed in a cage about 8 by 3 by 3 feet in size, which was covered with cheesecloth and left out in the open near the insectary at Cornell University. From June 7 to June 15, over one hundred specimens of *Monohammus scutellatus* were collected from the netting on the outside of the cage. During the first week in July a number of *Ips pini* adults were also collected on the outside of the cage. There seems to be no doubt that these beetles were attracted by the odor of these logs.

Usually the infestation is severe. In the bark of a white pine log 7 feet long and about 4 inches in diameter forty entrance holes were counted, which would mean from one hundred and twenty-five to one hundred and fifty beetles in this small log. Settling on a tree, the beetles run over the bark as though making a general survey, but very soon begin to bore into the bark. The part of the tree usually selected is the upper part of the trunk, where the bark is of medium thickness, as well as the larger limbs. A male usually starts the burrow and is closely followed by a female. The entrance hole is perfectly round, 1.5 millimeters in diameter. When the sapwood is reached a chamber from 6 to 8 millimeters wide and 2 millimeters deep is made between the wood and the outer bark. This is known as the nuptial chamber (Plate xx, 4), and here mating takes place.

The conclusion that the nuptial chamber is the mating place is based on three facts: (1) Mating has never been observed on the exterior of the log, although hundreds of beetles have been kept under observation both in the open and after being placed on pieces of white pine in the laboratory. (2) A long series of attempts were made to find the beetles in copula in the nuptial chamber. Males were placed on pieces of white pine, and after they had constructed the nuptial chamber one or two females were introduced into the openings. By the aid of slits made with a sharp knife the bark could be raised, exposing the chamber, and then replaced and held in position by means of pins or thumb tacks. Only once was any evidence obtained. This time a male was found with the penis everted. (3) Young beetles have been taken either from the pupal chamber or from burrows leading from this chamber, and placed on pieces of pine. These certainly had had no opportunity to copulate and they did not do so on the outside of the fresh pieces of pine. Yet these beetles reared young. From these three circumstances the evidence seems strong that the nuptial chamber is the place of copulation.

Occasionally a female starts a burrow. If a male follows, the usual nuptial chamber and galleries are made; but if no male enters, the nuptial chamber is omitted and the female burrows along for a distance without depositing eggs, and apparently later abandons the gallery.

From the nuptial chamber the female makes a tunnel running longitudinally of the trunk either up or down. This tunnel is known as the adult, or primary, gallery. It is cylindrical in form and about 2 millimeters in width — just large enough for the beetle to work in comfortably. In the meantime other females may enter, usually but two or three, and after mating they too start galleries; so that from the nuptial chamber from three to five galleries may extend out (Plate XX, 4). The male is thus polygamous. He remains at the entrance as though on guard, and pushes out the sawdust and excreta as it accumulates in the nuptial chamber from the galleries. He is stationed with the head inward and the excavation of the elytra toward the outside. In transferring the sawdust to the outside the beetle uses the legs, the excavation of the elytra, and the stiff hairs on the ventral surface of the body. On slight disturbances the flattened excavation is placed almost level with the outer margin of the bark, thus blocking the entrance into the burrow; but when touched with a twig or a pencil the beetle runs down one of the galleries and is found far in the gallery with the female when the bark is stripped off.

As the female constructs the gallery she makes small niches in the sides. In each niche she places an egg, and then packs in sawdust until the opening is even with the wall of the gallery, so that from the interior of the tunnel scarcely a sign of the niche can be distinguished. This habit is no doubt for the protection of the eggs from intruders that may gain access to the gallery. Niches may be placed on both sides of the tunnel, but are occasionally on one side only. When on one side only there is likely to be another gallery close alongside, and the female probably instinctively refrains from placing eggs on that side because the feeding area between these galleries would not be sufficient for the larvæ when they begin to tunnel and feed.

The primary galleries vary in length from 10 to 15 centimeters. The egg niches occur at regular intervals along these, varying in number from thirty-five to fifty-five per gallery. Some of the last niches have been found without eggs and the packing perfectly normal and undisturbed, indicating probably that the egg production had become exhausted. The egg-laying period is from twenty-five to thirty-five days and the rate of egg laying averages about one and one-half niches a day.

Along the course of the gallery there are found a few small holes in the roof leading to the outside, scarcely half a millimeter in diameter, possibly serving for ventilation or where some intruders have entered the gallery. Females are frequently found dead at the ends of their galleries, and occasionally the male is found dead at the entrance.

The new generation

The eggs hatch in five days at a temperature of 69° F. The young larvæ, on hatching, commence burrowing out into the cambium at right angles or obliquely from the primary gallery. The galleries thus made are known as the secondary, or larval, galleries or mines (Plate XX, 5). They may take an almost straight course or may be serpentine in form. When an infestation is severe they form a mass of interwinding mines. The sawdust and excreta are not removed but are packed in behind the larva as it works along.

The larval gallery is from 1 to 3 centimeters in length, with a width of 0.75 millimeter at the beginning and gradually enlarging as the larva increases in size until at the termination it is 1.75 millimeters in width. It ends in an enlargement about 5 millimeters wide, varying much in shape, which is known as the pupal chamber, for here the larva pupates (Plate XXI, 2).

The pupal period lasts about five days. The pupa becomes very active when exposed, moving its abdomen violently and wriggling out of the pupal chamber very quickly. After transformation the beetle remains in the pupal chamber for about four or five days, judging from the time required for the coloration to develop, and then it usually works in the cambium area for some time before emerging. Thus beetles of the new generation may sometimes be found in the log before the females of the first generation have finished egg laying. This apparently leads to a mixing of the generations, for the beetles of the new generation do not all leave the log at the same time. It has been found, at least where logs have been caged, that a half dozen or a dozen beetles would appear on the inside of the cage each day. Some of these reentered uninjured parts of the log from which they had emerged, and there brought up a new brood. It would seem, then, that the beetles of the new generation emerge in small numbers at a time and go off singly or in small companies to new breeding places. This view is supported by the fact that a few beetles would appear daily on the outside of the cage. At Ithaca there are at least two generations and under very favorable conditions there may be three. The beetles of the late generation, instead of emerging, work up into the bark and gradually become dormant as cold weather sets in.

DESTRUCTIVE POWER

The damage done by *Ips pini* is usually not of a serious character in itself. It has been reported as causing the death of certain pines and spruces, but these cases appear to be exceptional. The presence of pitch tubes is usually taken as evidence that a tree was attacked while living; but if a tree is attacked soon after it is felled, pitch tubes will be formed. However, this ability to cope with pitch, combined with the fact that the females instinctively make longitudinal galleries and so do not girdle the tree and thus endanger the food supply of their larvæ, would certainly indicate a possibility of serious damage being caused. The attacking of healthy trees may be a new tendency appearing in the habits of the beetle, or it may be that the ancestors attacked living conifers; but the habits of the species have been gradually changing, until now it is only when dead or dying trees cannot be found that the beetles return to the living. At any rate, normally it is only dying or recently dead trees that are attacked by this species.

Financial loss may be occasioned, then, in three ways as a result of the activities of the beetle: (1) by the attacking and killing of living trees; (2) by the attacking of injured trees which might otherwise have recovered; and (3) by opening the way for the entrance of fungi and ambrosia beetles, by which the log is soon rendered useless for lumber purposes.

CONTROL

Natural control

The pine bark beetle is kept under control by a number of natural agencies, such as the following:

1. A wet season makes it difficult for the beetles to work. The bark in time becomes wet and a considerable proportion of the larvæ fail to mature.

2. With this wet condition there develop fungi which seem to attack all stages of the insect.

3. Predatory enemies are usually common. At Ithaca, *Thanasimus dubius* Fab. have been found running over the logs, and in two instances were observed to devour adult *Ips pini*. *Enoclerus quadriguttatus* Oliv. are common on the logs. Running over the logs are usually a number of black carpenter ants, and one day a beetle was picked up with a pair of tweezers and offered to an ant, which readily accepted the prey. So possibly these large ants are important enemies. Several times, in pulling back the bark, partly eaten *Ips pini* adults have been found with *Cylistrix cylindricus* Payk. beside them. Whether or not these beetles preyed upon the pine bark beetles is difficult to say. Predacious staphylinid larvæ and adults, *Xantholinus cephalus* Serv. and *Quedius laevigatus* Gyll., are common in the burrows and no doubt devour eggs and larvæ. The following beetles have been taken in the burrows of *Ips pini*, some of which may be merely associates: *Platysoma coarctatus* Lec., *Hypophloeus*

parallelus Melsh., *Dryophthorus corticalis* Say, *Cossonus* sp., *Brontes dubius* Fab., *Deltometopus amoenicornis* Say, *Geodromicus strictus* Fauv. One species of Hemiptera, *Dufourielles ater* Dufour, has been taken in the burrows and may be predacious. Dr. Hopkins reports staphylinid larvæ, *Homolota* sp. (Staphylinidae), and clerid larvæ, *Hypophloeus parallelus* Melsh. (Tenebrionidae), as predacious on *Ips pini*, and also two clerids taken on trees infested with *Ips pini* and *Ips caelatus* and probably predacious on these, *Trichodes simulator* and *Clerus quadriguttatus*. Under the elytra and in the excavations of the elytra are frequently found mites; just how much injury these do to the beetles is difficult to say. Also under the elytra are very frequently found clusters of nematode worms. These are about 0.75 millimeter long and are attached by means of suckers at the end. There are usually two or four clusters attached between the first and second, and the third and fourth, abdominal segments. These have not been found within the bodies of the beetles, and here again it is difficult to say what harm, if any, is done.

4. Parasites are probably numerous. It is impossible to remove larvæ and pupæ from a log and keep them for the purpose of rearing parasites from them. The best that can be done is to place the logs in cages covered with cheesecloth, catch all insects that emerge from the logs, and judge which are likely to be parasites. In this way the following parasites have been obtained: Hymenoptera, *Roptrocerus eccoptogaster* Ratz., *Spathius* sp., *Microbracon* sp., and a chalcid; Diptera, *Agromyzidae* sp. and *Phyllomyza* sp. Dr. Hopkins reports one parasite named *Lochites* sp. b.

Artificial control

Removal of the bark will cause the death of all larvæ and pupæ of the pine bark beetle. If a little care is taken in the removal and the bark is burned immediately, a large number of the adults may also be destroyed. Removal and burning of the bark in winter where adults are known to be in hibernation will do much to lessen attacks in the season following. Where water is available the placing of newly felled logs in the water will prevent injury by the beetles.

COMMON ASSOCIATES

Beetles commonly found associated with *Ips pini* are as follows:

(1) In the part of the tree where *Ips pini* works: *Monohammus scutellatus* Say, *Rhagium lineatum* Oliv., *Pytho americanus* Kirby, *Ips longidens* Swaine, *Pityogenes* sp., buprestid species.

(2) In other parts of the tree: All the above have been found, and in addition the following: *Ips caelatus* Eich., *Ips calligraphus* Germ., *Gnathotrichus materiarius* Fitch, *Hylurgops pinifex* Fitch, *Monohammus confusor* Kirby.

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SOME EFFECTS OF OXYGEN AND CARBON DIOXIDE ON NITRIFICATION AND AMMONIFICATION IN SOILS

J. K. PLUMMER

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SOME EFFECTS OF OXYGEN AND CARBON DIOXIDE ON NITRIFICATION AND AMMONIFICATION IN SOILS[1]

J. K. Plummer

Since the theory of nitrification was advanced by Schlœsing and Müntz in 1878, the factors that affect the formation of nitrates and ammonia in soils have been studied rather extensively. It is generally believed that aëration is most commonly the limiting factor, yet there is little conclusive evidence to show whether the effect is due to the specific action of the gases contained in the soil atmosphere. Soils are likely to vary considerably in the relative quantities of oxygen and carbon dioxide held in the pore spaces, this variation depending largely on the relative quantities of easily decomposable organic matter present. The effect of oxygen and carbon dioxide on nitrification and ammonification in soils has been studied to a limited extent, but the evidence obtained seems insufficient to justify any very definite conclusions, as the following review shows.

REVIEW OF EARLIER INVESTIGATIONS

The present theory of nitrification was advanced by Schlœsing and Müntz (1877, a and b, and 1878).[2] These investigators were led to believe that the formation of nitrates is due to some form of life. They state, without presenting data to prove, that there is a direct chemical union of oxygen and nitrogen, brought about by ferments. The oxygen absorbed during the period of nitrification, they say, shows the supply to be sufficient for the oxidation that takes place.

Warington (1892) found that a liberal supply of oxygen is very favorable to nitrification.

Marchal (1893), while working with ammonifying bacteria, found that when the oxygen supply was sufficient some of the ammonifiers were purely aërobic in their behavior. When the conditions became anaërobic, some of these organisms, *Bacillus mycoïdes* especially, behaved as denitrifying bacteria and destroyed the nitrates. Marchal states the conditions best adapted to ammonification, which are thoro aëration, slightly alkaline media, and a temperature of 30° C.

Dehérain (1893) and King and Whitson (1901) compared soil stirred and soil not stirred, and found that nitrates were produced more rapidly in the stirred soils. This they attributed to better aëration.

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[1] This investigation was conducted under the direction of Dr. James A. Bizzell.

[2] Dates in parenthesis refer to bibliography, page 328.

Godlewski (1896) observed, from a series of experiments with solutions, that a small amount of carbon dioxide is necessary for the action of the nitrate organism. He found also that the carbon of magnesium carbonate is not suitable for the functions of these bacteria.

Schlœsing (1897) found, after a study of nitrification in clay and in sandy soils, that, contrary to the accepted belief, nitrification went on as rapidly in compact clay soils as it did in coarser-grained soils, when the available water in each case was the same. The experiments of Fischer (1911) led to the same conclusion.

Coleman (1908) found, from a number of experiments, that a supply of carbon dioxide is necessary for both the nitrite and the nitrate organism.

Owen (1908), after a rather extended study of the question, decided that carbon dioxide has no effect on nitrification. In his work nutrient solutions and pure cultures were employed. Air free of carbon dioxide was forced thru 1000-cubic-centimeter flasks containing the solutions. Other flasks contained an atmosphere of pure carbon dioxide.

Stevens and Withers (1909, a and b, and 1910, a and b) concluded from their results that tests made in solutions are not adequate to indicate the behavior of nitrifying or of ammonifying bacteria as compared with their behavior in the soil. These authors state also that nitrification does not take place in sealed flasks.

Effront (1909) showed that ammonification may proceed either in a strictly anaërobic medium with the butyric ferment, or in an aërobic medium in the soil.

Kelley (1911) found, while working with the inundated soils of Hawaii, that ammonia is formed in these soils in their natural state; also, that swamp rice plants prefer this form of nitrogen.

Stoklasa (1912) states that the carbon dioxide evolved can be used as a measure of the bacterial activities in the soil. Thus, where there is greatest nitrification there will be found the greatest production of carbon dioxide.

Temple (1912) determined nitrification in twenty-six Georgia soils. In twenty-four of these, tankage was nitrified more readily than was ammonium sulfate or ammonium chloride. Various other materials produced the same results as did tankage. When calcium carbonate was used, ammonium sulfate and ammonium chloride produced as great a quantity of nitrates as did the other nitrogenous compounds.

SCOPE OF PRESENT WORK

The citations just given will suffice to show the diversity of opinion regarding the relation of oxygen and carbon dioxide to the formation of nitrates and ammonia in soils. The discrepancies are probably due in many cases to the lack of uniformity in experimental methods. Practically all previous investigators on this subject have used the solution culture method for determining the rate and extent of nitrification and ammonification. This method, however, does not seem suitable for the solution of the problem in question, since the diffusion and absorption of atmospheric gases is not the same as that which takes place when soil is used as the medium.

Again, there seems to be nothing in the recorded data to indicate whether the effects of these gases are specific or whether they are indirect. For example, is carbon dioxide toxic to the nitrification or does its presence merely mean a smaller quantity of oxygen? With the hope of answering questions of this character the following detailed study was undertaken.

RELATION OF OXYGEN AND CARBON DIOXIDE TO NITRIFICATION IN SOILS

Method of investigation

In order to maintain a constant quantity of gas, or even to approximate such a condition, it seemed necessary to conduct the nitrification in hermetically sealed vessels. Otherwise there would be rapid diffusion, and equilibrium would soon be established with gases of the atmosphere. Stevens and Withers (1910 b) state that nitrification does not proceed in sealed flasks. This conclusion is not in harmony with results obtained in the present work, as the data show.

Some preliminary experiments were found necessary in order to determine the best method for preparing the gas mixtures and confining them in the flasks.

In all the experiments 500-cubic-centimeter Erlenmeyer flasks were used. These were fitted with three-hole rubber stoppers, which had been previously boiled in paraffin to prevent absorption of the gases by the rubber. A glass tube bent to serve as a manometer when closed with mercury was placed in one hole of each stopper, so that any change in pressure could be readily observed. The other two holes of the stoppers were fitted with glass tubes, to allow the gases to be forced in and out. (Fig. 66, page 309.) One hundred milligrams of ammonium sulfate was added in solution to 100 grams of fresh soil to which had been added one-half gram of calcium carbonate. Moisture and nitrate determinations were made at the beginning of each experiment, and the water content was brought to 25 per cent, calculated to the dry weight of soil in all cases. Nitrates were determined by the well-known phenoldisulfonic acid method.

The water extracts were made according to the directions given by Schreiner and Failyer (1906). This method consists in adding 500 cubic centimeters of water to 100 grams of soil, stirring for three minutes, allowing to stand for twenty minutes, and filtering the supernatant liquid through a Pasteur-Chamberlain filter tube.

Oxygen and carbon dioxide were determined by absorption in alkaline pyrogallol and caustic potash, respectively, according to the methods described by Dennis (1913).

The soil used thruout the work was Dunkirk clay loam, taken from under sod directly to the east of the experimental plots on Caldwell Field at Cornell University. This soil was selected because of its low initial nitrate content.

The gas mixtures were made directly in the flasks. The volume of the soil and the water was calculated, and this volume was deducted from the total volume of the flasks. With mercury as the confining liquid, the necessary amount of oxygen to give the desired mixtures was forced in. Previous to adding the oxygen, black rubber gas tubing was placed over the ends of the outlet tubes. After the mixtures were made these were plugged with glass rods. The results of this experiment are given in table 1:

TABLE 1

Flask no.	Composition of gas mixture added		Time of incubation (days)	Nitrates (NO_3) (parts per million dry soil)	Composition of gas mixture at end of experiment	
	Oxygen (per cent)	Nitrogen (per cent)			Oxygen (per cent)	Carbon dioxide (per cent)
1	95	5	14	115.9	30.2	8.4
2	95	5	14	142.7	29.4	9.8
3	95	5	21	204.5	22.4	5.8
4	95	5	21	238.9	20.8	6.0
5	38.2	61.8	14	182.5	23.6	10.9
6	38.2	61.8	14	282.0	12.6	8.3
7	38.2	61.8	21	609.4	10.0	8.0
8	38.2	61.8	21	551.9	5.6	12.0
9	25	75	14	302.9	18.1	8.7
10	25	75	21	493.5	8.3	10.0
11	25	75	21	501.5	8.0	11.6
12	21	79	14	267.1	10.1	5.4
13	21	79	14	232.1	12.0	5.2
14	21	79	21	365.0	12.7	5.9
15	21	79	21	414.5	11.0	6.8

The results obtained from this experiment show that nitrification takes place in closed flasks when calcium carbonate is added with the ammonium sulfate. At the end of fourteen days there was little difference in nitrates formed between the various concentrations of the gas mixtures. At the end of twenty-one days, however, the mixture containing 38.2

per cent of oxygen gave decidedly the highest quantity of nitrates. Just why there should not have been a greater difference due to variations in the oxygen content at the end of fourteen days cannot be explained, unless in those flasks there was greater diffusion thru the rubber connections. In flasks 3 and 4, less carbon dioxide was found at the end of three weeks than in flasks 1 and 2 at the end of two weeks. It seems improbable that there should be so much greater proportionate losses in oxygen content in flasks 1, 2, 3, and 4, with a low nitrate content, than in flasks 7 and 8, which had a higher nitrate content than any in the series. This would suggest that diffusion of the gases had taken place, and it would seem that the greater diffusion had occurred in those flasks that contained the least nitrogen and the greatest amount of oxygen. This is quite reasonable, for in the flasks containing almost pure oxygen there would be a tendency for more nitrogen to diffuse, such flasks acting as a vacuum toward this element.

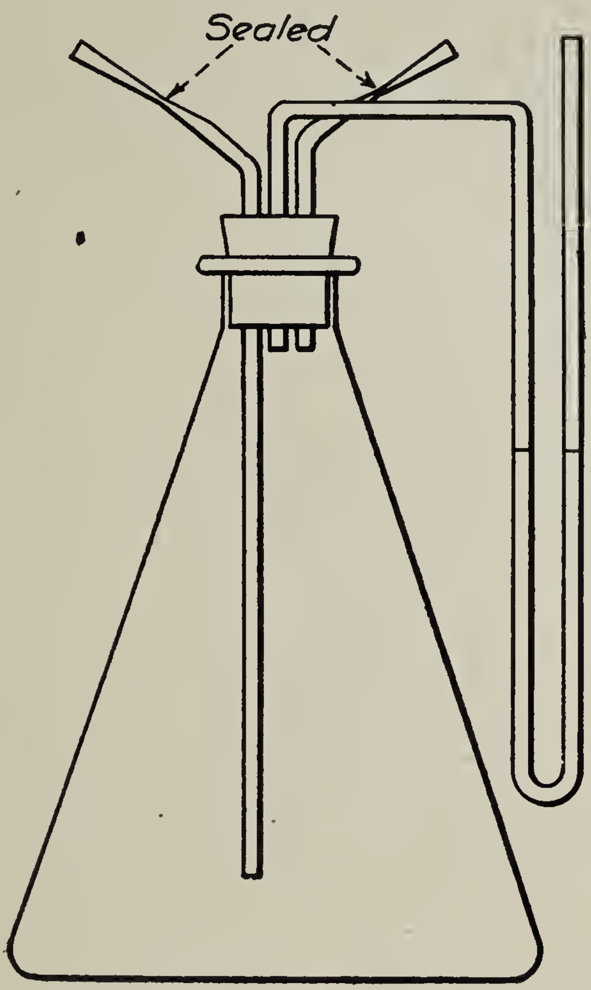

FIG. 66. FLASK USED IN EXPERIMENTS

An experiment was begun to determine whether diffusion occurred thru the rubber connections. In this experiment 95 per cent of oxygen was forced thru flasks fitted similarly to those the results from which are given in table 1 but containing nothing except the oxygen gas. The oxygen was forced thru the flasks for five minutes, at the end of which time samples of the gas leaving the flasks were collected and analyzed. The results are given in table 2:

TABLE 2

Flask no.	Per cent of oxygen at beginning of experiment	Per cent of oxygen at end of experiment	Per cent of oxygen lost
1	94.8	82.8	12.7
2	94.8	82.8	12.7
3	95.0	84.5	11.5
4	95.2	83.9	11.7

These results showed that this method could not be used, for there was a constant interchange of the gases in the flasks with those of the atmosphere.

It was then decided to use glass tubes drawn out to capillary size, and to seal them after the mixtures had been forced thru the flasks until the air had been displaced. The difficulty of getting a sample for analysis when the mixtures were made directly in the flasks made it necessary to devise some other mode of procedure.

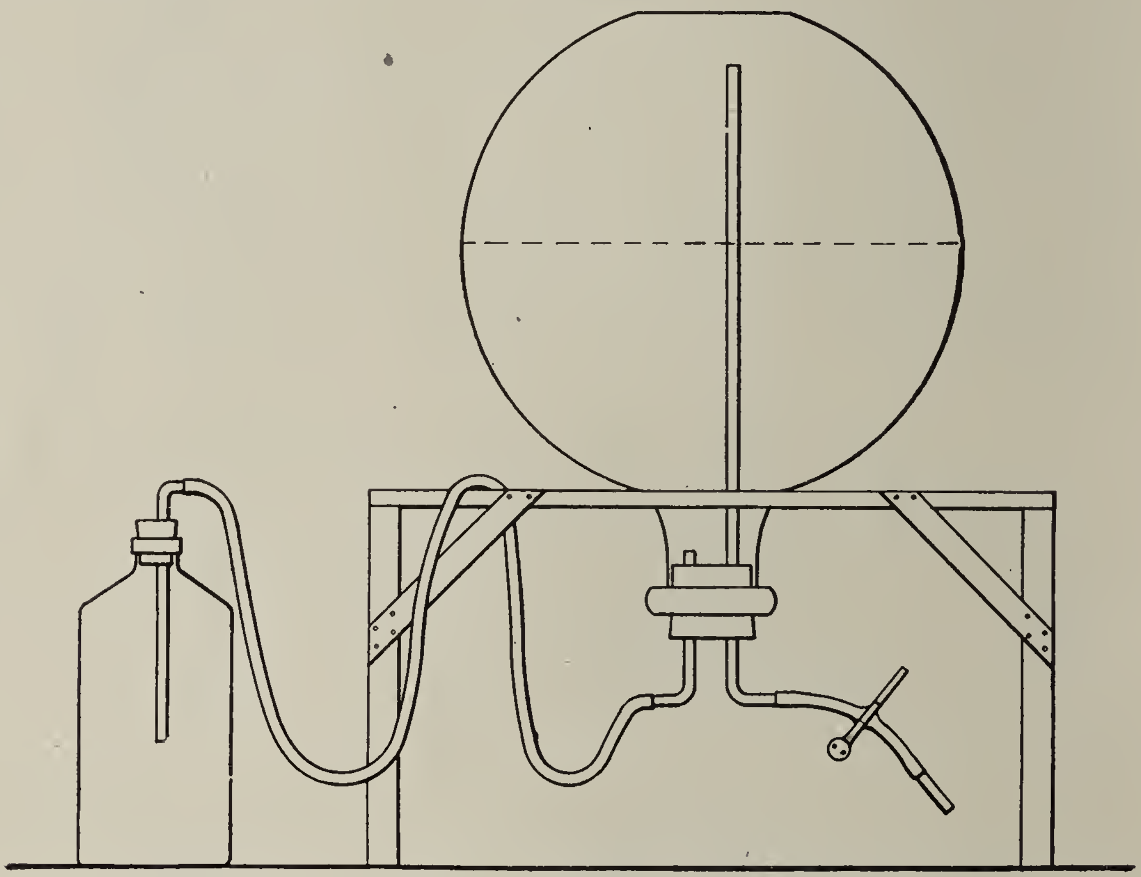

FIG. 67. GASOMETER USED IN EXPERIMENTS

In this experiment it was necessary to ascertain whether there was a loss in the gases thru the rubber stoppers, which had been boiled in paraffin. The exact procedure as given above was repeated, except that the tubes were drawn out and sealed after the flasks had been filled with oxygen (fig. 66). The results are given in table 3:

TABLE 3

Flask no.	Per cent of oxygen at beginning of experiment	Per cent of oxygen at end of 14 days
1	94.8	94.7
2	94.8	94.7
3	95.0	95.0
4	95.0	94.8

These results show that there is no diffusion of oxygen thru the rubber stoppers when they are coated with paraffin. This method of procedure was adopted in all the subsequent work.

The gasometer in which the mixtures were made is shown in figure 67.

Effect of mixtures of oxygen and nitrogen on nitrification

Nitrates produced

It having been found that nitrification would take place in sealed flasks with Dunkirk clay loam when lime was used, experiments were set up to study the effect of oxygen and nitrogen on nitrification. In each of the following experiments 100 grams of fresh soil, screened thru a 3-millimeter sieve, was used. Unless otherwise stated, 0.5 gram of calcium carbonate was mixed with each 100 grams of soil, to make the conditions most favorable for nitrification. The mixing was done all at one time — that is to say, the total amount of soil for the different mixtures was weighed out, and the calcium carbonate was mixed in with this. As in the other experiments, the water content was brought to 25 per cent, calculated to the dry weight of soil. One hundred milligrams of ammonium sulfate was added to the water put in. The soil was spread out on a large glass plate and the solution added in the form of a spray. The soil was then thoroly mixed, and placed in the flasks in 100-gram portions. Mercury was placed in the manometer tubes, which held strips of paper graduated in centimeters.

The gas mixtures were made in the gasometer shown in figure 67, and were forced into the flasks by raising the level bottle. In a number of instances the gas that had passed thru the flasks was analyzed. It was found that by forcing six liters of the gas mixture thru, practically all the atmospheric air had been displaced — this amount being twelve times the volume of the flasks. Rubber tubing that had been boiled in paraffin was placed on the delivery and exit tubes and clamped with stopcocks. The flasks were then placed in the incubator until equilibrium was established in pressure at the new temperature of 30° C. This usually required from ten to fifteen minutes. (It is recognized that there may have been slight diffusion of gases thru the rubber tubing, but this could not be avoided.) The cocks were momentarily opened in order to allow the increase in gas volume due to the rise in temperature to escape, after which the tubes were sealed. The treatments were made in quadruplets, two of which were analyzed at the end of fourteen days and the other two at the end of twenty-eight days. The results, given in tables 4 and 5, are the averages of from two to six determinations for each treatment. All the experiments were repeated at least twice, and some as many as four times. It was not always possible, however, to obtain exactly the same gas mixture in repeating the treatments. These differences in gas mixtures were small and are given exactly as the analysis showed at the beginning of the experiments. In some cases the difference in nitrate content between the duplicate flasks was greater than was found in those flasks with different gas mixtures, but this was rather unusual. The nitrates are given as increases due to the different treatments. These figures were obtained by subtracting the nitrate content calculated to dry soil, at the beginning, from the total at the end, of the various experiments. This method of calculation was permissible, since the nitrate content in the fresh soil was nearly the same in all cases. The averages of the results obtained with the oxygen-nitrogen mixtures are given in table 4:

TABLE 4

Composition of gas mixture added		Time of incubation (days)	Nitrates (NO_3) (parts per million dry soil)	Composition of gas mixture at end of experiment	
Oxygen (per cent)	Nitrogen (per cent)			Oxygen (per cent)	Carbon dioxide (per cent)
21	79	14	323.1	1.6	9.3
21	79	28	368.8	None	10.6
30	70	14	388.6	3.8	11.2
30	70	28	499.5	0.7	13.1
40	60	14	727.9	8.1	14.4
40	60	28	957.9	2.1	17.1
45	55	14	707.8	15.0	12.2
45	55	28	900.8	7.6	16.7
50	50	14	590.0	22.7	11.8
50	50	28	742.9	16.4	15.8
55	45	14	409.3	33.7	9.1
55	45	28	815.7	15.8	15.6
60	40	14	355.5	40.2	9.1
60	40	28	725.9	27.8	14.9
70	30	14	290.9	52.5	9.1
70	30	28	661.9	45.0	14.9
80	20	14	232.4	68.2	7.7
80	20	28	346.8	60.1	13.8
85	15	14	219.3	71.7	8.3
85	15	28	336.1	65.9	13.4
95	5	14	249.9	86.2	5.2
95	5	28	271.3	78.1	10.5

From the results shown in this table it can readily be seen that oxygen has a stimulating effect on nitrification. Beginning with the mixture containing 21 per cent of oxygen and 79 per cent of nitrogen (ordinary air), there are marked increases in the production of nitrates as the oxygen supply is increased until 40 per cent is reached. This holds good for both fourteen and twenty-eight days incubation. With 50 per cent of oxygen there are somewhat less nitrates formed than with 45 per cent of oxygen. As the supply of oxygen is increased beyond this point there is a rather regular decrease in nitrate production. It would thus seem that the gas mixtures containing from 40 to 45 per cent of oxygen are the most favorable to nitrification in this soil. These results show that the higher amounts of oxygen, while depressing the formation of nitrates, do not entirely prevent it. There are 73.2 parts per million less nitrates in the flasks containing 95 per cent of oxygen at the end of fourteen days than in the flasks containing ordinary air. The difference for twenty-eight days is 97.5 parts per million. This is not what would be expected, for it would seem that the nitrates produced during the first fourteen days would rarify the oxygen somewhat, and thus, the oxygen being further diluted with carbon dioxide, better conditions for nitrification would be obtained. There is no apparent explanation for this depressing effect.

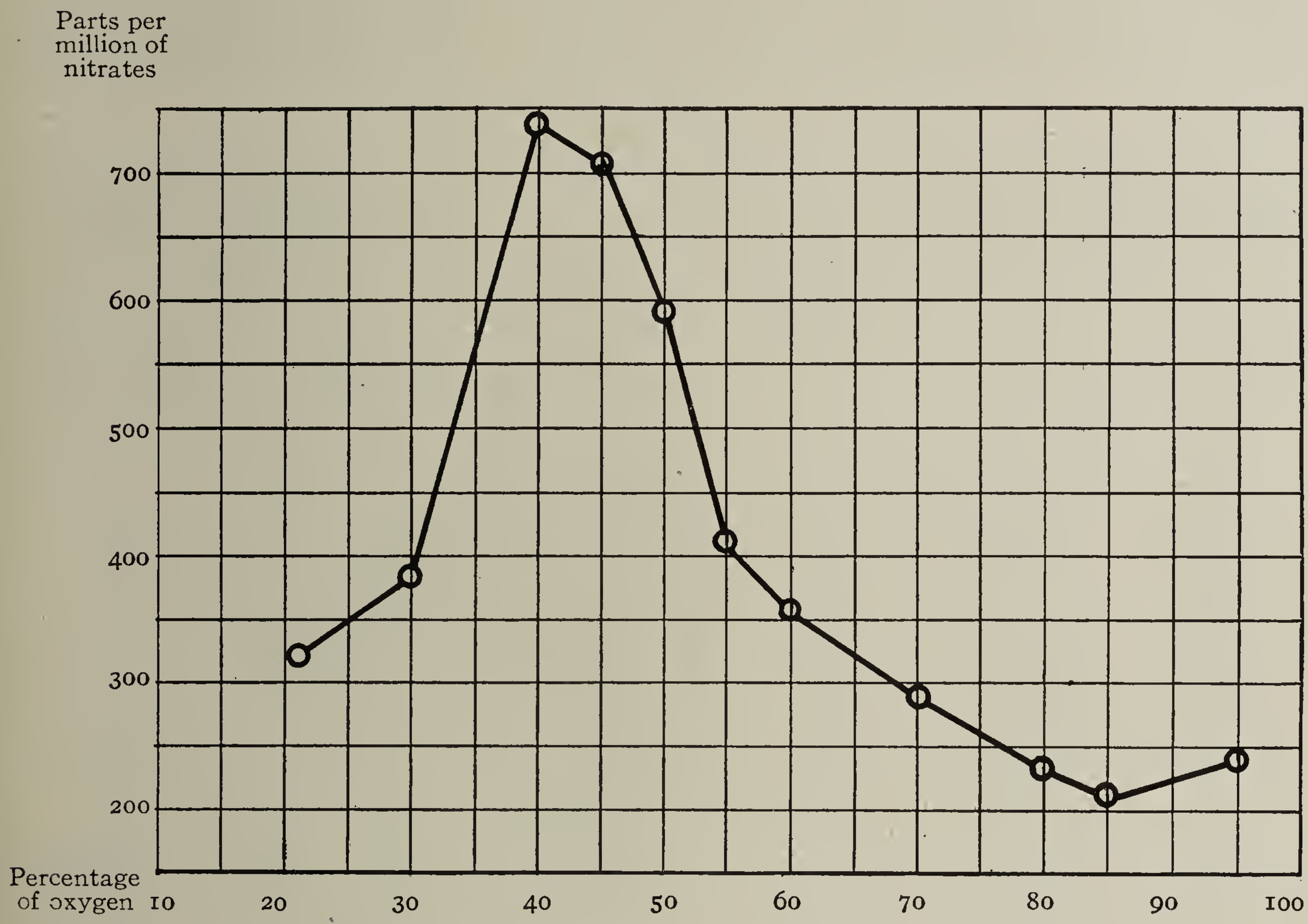

Fig. 68. PRODUCTION OF NITRATES WITH INCREASE IN OXYGEN CONTENT, AT THE END OF FOURTEEN DAYS

One noticeable point shown by the composition of the mixtures at the end of fourteen and of twenty-eight days is the large consumption of oxygen. In the flasks containing 21 per cent of oxygen at the beginning, there was only 1.6 per cent at the end of fourteen days and none at the end of twenty-eight days. In the flasks originally containing 40 per cent of oxygen, there was only 8 per cent and 2 per cent at the end of fourteen and of twenty-eight days, respectively. This loss of oxygen is always greater than the carbon dioxide produced, and increases regularly with the nitrates formed. The production of nitrates with increases in the oxygen content of the various gas mixtures at the end of fourteen days is shown graphically in figure 68.

The preceding results were obtained with soil to which ammonium sulfate and calcium carbonate had been added. It was decided to try oxygen and nitrogen mixtures with the fresh soil, without the addition of ammonium sulfate or calcium carbonate. The results are given in table 5:

TABLE 5

Composition of gas mixture added		Time of incubation (days)	Nitrates (NO_3) (parts per million dry soil)	Composition of gas mixture at end of experiment	
Oxygen (per cent)	Nitrogen (per cent)			Oxygen (per cent)	Carbon dioxide (per cent)
21	79	14	99.3	8.2	6.1
21	79	14	95.2	9.6	5.9
31	69	14	117.6	14.5	7.6
31	69	14	117.6	15.6	8.8
43	57	14	152.4	22.0	10.5
43	57	14	194.8	21.8	10.1
48	52	14	147.0	29.3	10.6
48	52	14	152.4	27.7	11.0
52	48	14	135.5	32.5	9.5
52	48	14	148.9	34.3	9.8
58	42	14	117.6	42.3	8.9
58	42	14	108.6	43.7	9.4
63	37	14	95.2	48.3	10.0
63	37	14	95.2	49.1	8.8
69	31	14	95.2	53.1	8.9
69	31	14	95.2	52.2	9.0
76	24	14	83.0	62.3	8.6
76	24	14	83.0	61.6	8.8
93.5	6.5	14	53.9	84.0	4.3
93.5	6.5	14	50.4	85.1	3.8

In this case, as in the experiments in which lime and ammonium sulfate were added, there is a stimulating effect on nitrification caused by an increase in the oxygen content of the atmosphere in the flask. This increase is greatest in the mixtures containing from 43 to 52 per cent of oxygen. Tho the degree of nitrification is much less when there is no calcium carbonate nor ammonium sulfate, the differences in the two experiments run parallel.

The quantity of carbon dioxide evolved is also lower than in the corresponding experiments in which lime was used. This would tend to show that a basic condition is best suited for the production of this gas.

Relation of oxygen consumed to nitrates formed

The amount of oxygen not accounted for by the carbon dioxide formed plus the oxygen at the end of the experiment, was calculated to parts per million of oxygen (by weight) lost per 100 grams of dry soil. The weight of oxygen corresponding to that which went into the nitrates was calculated for the different mixtures. The results of these calculations, which were made from the averages of the oxygen-nitrogen treatments shown in table 4, are given in table 6:

TABLE 6

Composition of gas mixture added		Time of incubation (days)	Nitrates (NO_3) (parts per million dry soil)	Per cent of oxygen not recovered as such	Parts per million of oxygen and nitrogen found	Parts per million of oxygen not recovered as such
Oxygen (per cent)	Nitrogen (per cent)					
21	79	14	323.1	10.3	250.4	165.2
21	79	28	368.8	10.4	285.8	166.4
30	70	14	388.6	14.8	301.6	321.9
30	70	28	499.5	16.3	387.1	372.8
40	60	14	727.9	17.1	564.1	522.2
40	60	28	957.9	20.8	742.4	635.3
45	55	14	707.8	17.8	548.5	611.5
45	55	28	900.8	20.7	698.1	711.2
50	50	14	590.0	13.0	457.2	496.4
50	50	28	742.9	17.8	575.4	680.6
55	45	14	409.3	13.4	317.2	562.7
55	45	28	815.7	20.1	630.0	844.2
60	40	14	355.5	10.7	275.4	490.3
60	40	28	725.9	17.3	562.4	793.9
70	30	14	290.9	6.8	225.1	369.2
70	30	28	661.9	10.1	512.9	531.6
80	20	14	232.4	4.1	180.9	250.5
80	20	28	346.8	6.2	268.3	378.8
85	15	14	219.3	3.0	169.9	194.6
85	15	28	336.1	5.7	252.1	369.8
95	5	14	249.9	3.8	193.6	275.6
95	5	28	271.3	6.9	200.3	500.4

It can readily be seen from the calculations given in table 6 that the oxygen consumed during the processes that went on in the flasks was greater than that required to form nitrates. With four exceptions this was the case, and these occurred where the oxygen supply was found to be limited. It seems to the writer that these results are consistent and that the excess is great enough to justify the conclusion that oxygen is used in other processes than in forming nitrates. The amount of oxygen not recovered by the analyses either as oxygen or as carbon dioxide is greatest when the nitrate production is at its maximum.

The results given in table 6 are shown graphically in figure 69.

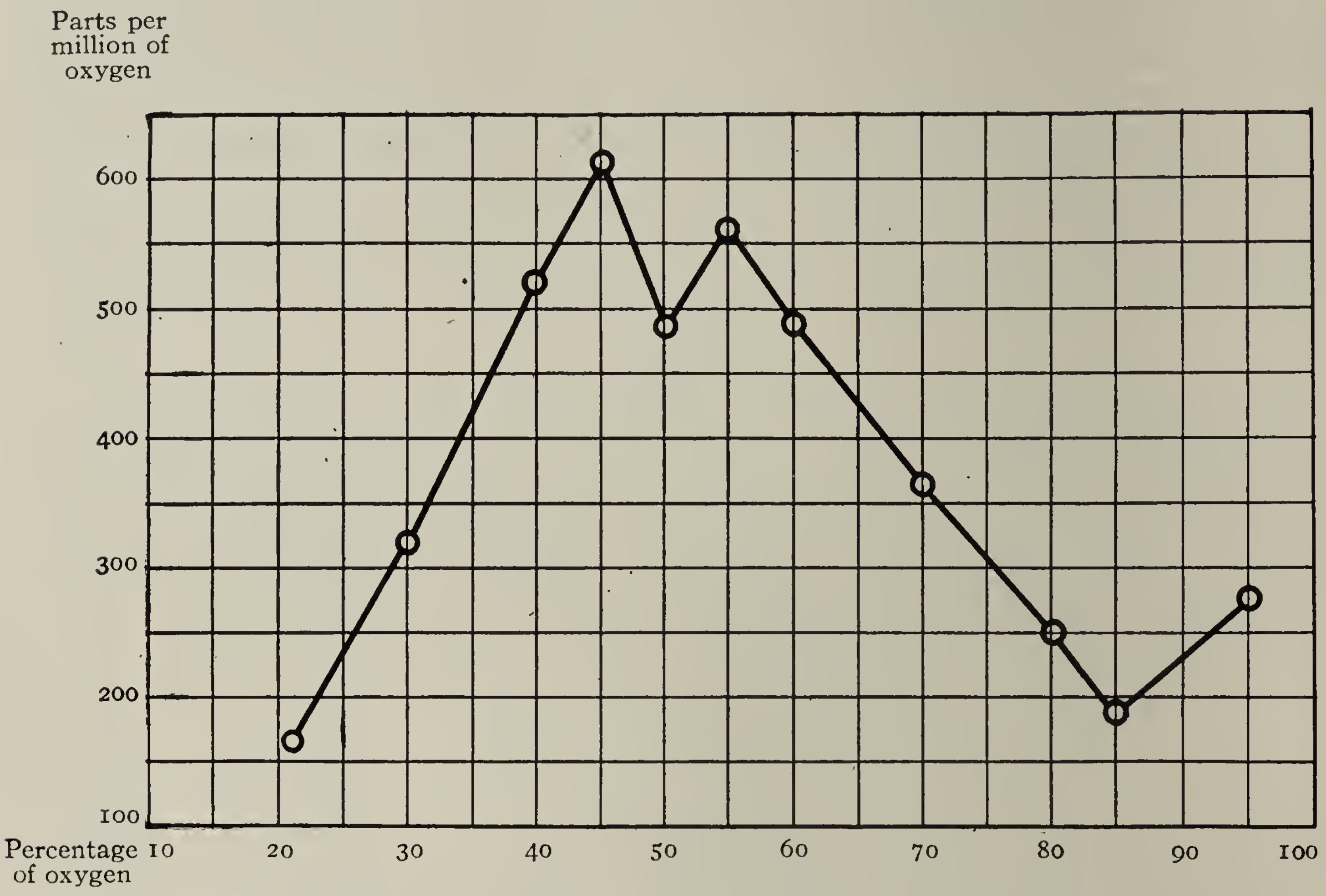

Fig. 69. OXYGEN FIXED BY BACTERIA WITH INCREASE IN OXYGEN CONTENT, AT THE END OF FOURTEEN DAYS

Relation of carbon dioxide produced to nitrates formed

Another interesting point brought out by table 4 is the production of carbon dioxide. The amount formed increases fairly regularly with the nitrates produced. This is in line with the work of Stoklasa (1912), who states that the carbon dioxide produced can be used as a measure of bacterial activity in soils. The amount of carbon dioxide formed as shown in table 4 can be better illustrated by computing the percentages found to parts per million formed by 100 grams of soil. This is done in a manner similar to that followed in making the oxygen calculations, computing first the volume occupied by the gas mixtures and then the volume of carbon dioxide produced. One cubic centimeter of carbon dioxide weighs .00198 gram. The results of such calculations taken from table 4 are given in table 7.

Tho ammonium sulfate was used as the nitrifiable material, the uniform increase of carbon dioxide formed with nitrates produced is entirely reasonable. The conditions in the flasks were the best possible for bacterial

TABLE 7

Composition of gas mixture added		Time of incubation (days)	Nitrates (NO_3) (parts per million dry soil)	Parts per million carbon dioxide produced by 100 grams of soil
Oxygen (per cent)	Nitrogen (per cent)			
21	79	14	323.1	998.5
21	79	28	368.8	1,135.9
30	70	14	388.6	1,200.0
30	70	28	499.5	1,403.0
40	60	14	727.9	1,543.0
40	60	28	957.9	1,832.0
45	55	14	707.8	1,307.5
45	55	28	900.8	1,789.6
50	50	14	590.0	1,265.6
50	50	28	742.9	1,693.2
55	45	14	409.3	978.6
55	45	28	815.7	1,671.7
60	40	14	355.5	978.6
60	40	28	725.9	1,596.7
70	30	14	290.9	978.6
70	30	28	661.9	1,596.7
80	20	14	232.4	824.4
80	20	28	346.8	1,278.8
85	15	14	219.3	889.6
85	15	28	336.1	1,462.0
95	5	14	249.9	557.2
95	5	28	271.3	1,068.0

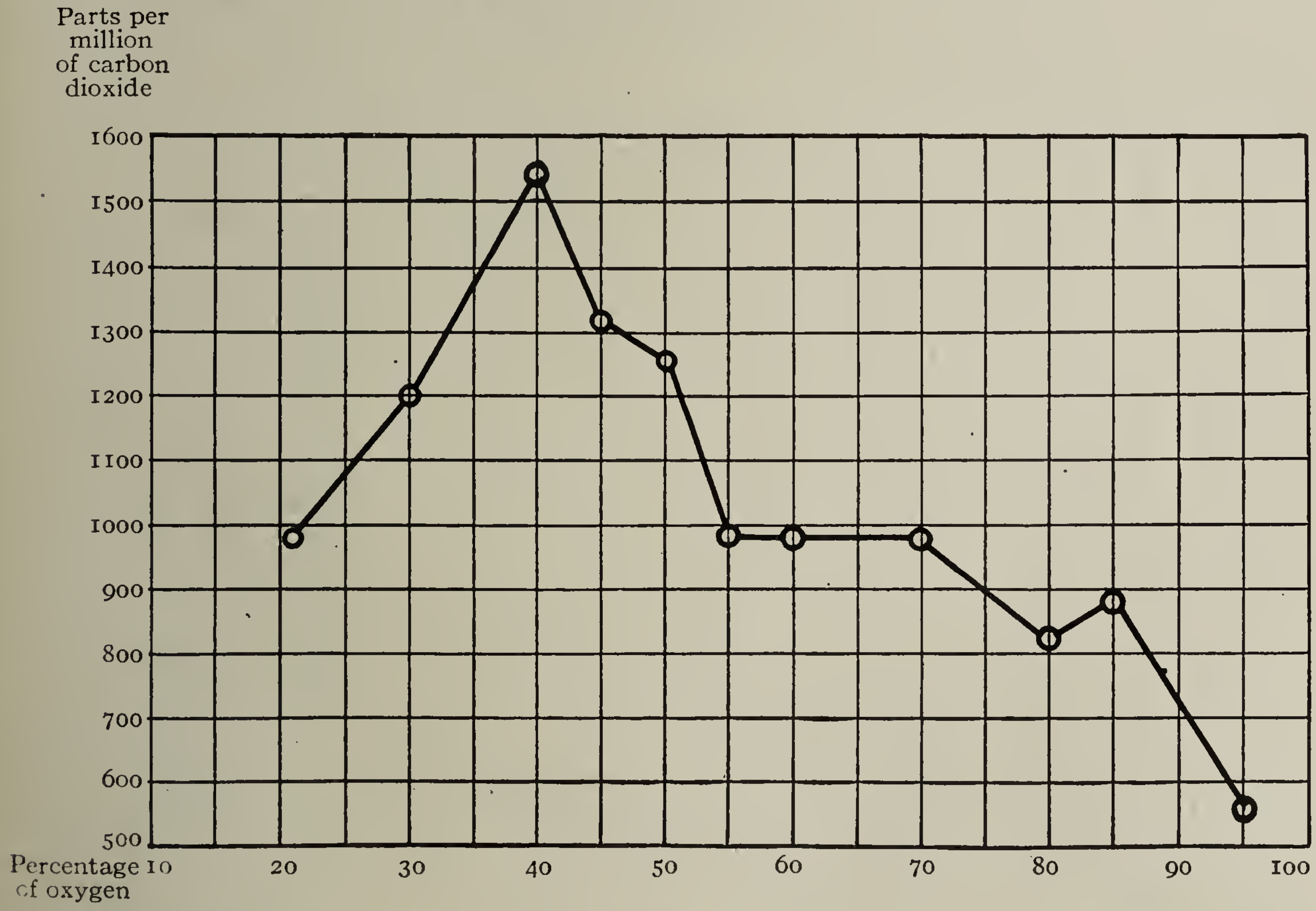

FIG. 70. PRODUCTION OF CARBON DIOXIDE WITH INCREASE IN OXYGEN CONTENT, AT THE END OF FOURTEEN DAYS

activities, and undoubtedly some of the nitrogen of the organic content of the soil was nitrified; hence the destruction of the organic matter. It is, then, reasonable to expect that where there is the greatest decomposition of such material — and such must be the case before the nitrogen can be converted to nitrates — there will be the greatest quantity of carbon dioxide formed.

The results shown in table 7 are plotted in figure 70.

Effect of mixtures of carbon dioxide and nitrogen on nitrification

The influence of oxygen-nitrogen mixtures on nitrification having been studied, it was decided to ascertain what would be the effect of mixtures of carbon dioxide and nitrogen. The nitrogen was obtained by forcing ordinary air thru a series of gas-washing bottles containing alkaline pyrogallol to remove the oxygen. In this way a very pure form of nitrogen was obtained, in some cases analyzing as high as 99.2 per cent nitrogen.

The results of an experiment with these mixtures are given in table 8. This experiment was repeated with essentially the same results.

TABLE 8

Composition of gas mixture added			Time of incubation (days)	Nitrates (NO_3) (parts per million dry soil)	Composition of gas mixture at end of experiment	
Oxygen (per cent)	Carbon dioxide (per cent)	Nitrogen (per cent)			Oxygen (per cent)	Carbon dioxide (per cent)
21	..	79	14	161.3	3.4	7.1
21	..	79	14	168.0	4.1	6.9
..	73	27	14	—14.6*	None	72.8
..	73	27	14	—14.6	None	73.2
..	61	39	14	—14.6	None	60.0
..	61	39	14	—14.6	None	60.5
..	52	48	14	—14.6	None	51.6
..	52	48	14	—14.6	None	51.7
..	40	60	14	—14.6	None	40.0
..	40	60	14	—14.6	None	39.8
..	30	70	14	—14.6	None	29.7
..	30	70	14	—14.6	None	29.8
..	24	76	14	—14.6	None	24.2
..	24	76	14	—14.6	None	23.9
..	99	..	14	—14.6	None	0.8
..	99	..	14	—14.6	None	0.6

*Minus sign denotes that there were less nitrates than at the beginning of the experiment.

From the results presented in table 8 it is quite evident that the mixtures composed of carbon dioxide and nitrogen are not favorable to nitrate formation in soils. There were 14.6 parts per million of nitrates at the beginning of the experiment, and in all cases there was only a trace at the end. The denitrifying bacteria apparently destroyed the nitrates present at the beginning.

Effect of mixtures of carbon dioxide and oxygen on nitrification

Certain concentrations of oxygen mixed with nitrogen appeared to increase the formation of nitrates beyond that which takes place in the atmosphere. The question arose, Does this hold true for oxygen when in association with carbon dioxide? Generally it is considered that the inert gas nitrogen plays no part in the actual formation of nitrates. Any appreciable variation between the results obtained with the same concentrations of oxygen diluted with nitrogen and with carbon dioxide, must be due to the latter gas. The experiments to ascertain the effect of mixtures of carbon dioxide and oxygen were conducted exactly as were those with the oxygen-nitrogen mixtures. The carbon dioxide used was of the highest purity, analyzing 99.8 per cent pure. The oxygen used contained 5 per cent of nitrogen. The average results obtained from these experiments are given in table 9.

It appears from table 9 that the maximum nitrate production resulted with the mixture composed of 60 per cent of carbon dioxide and 35 per cent of oxygen. With the oxygen-nitrogen mixtures the maximum quantity of nitrates was produced by the mixtures containing from 40 to 45 per cent of oxygen (table 4). Taking into account the experimental error, these results are therefore in close agreement with those of the experiments with the oxygen-nitrogen mixtures.

A point of interest brought out in table 9 is the lower amount of nitrates produced at the end of twenty-eight days with the mixture containing 75 per cent of carbon dioxide and 20 per cent of oxygen than was found at the end of fourteen days. A glance at the composition of the mixture at the end of each experiment shows that the oxygen supply was very low at the end of fourteen days — only 2 per cent — while at the end of twenty-eight days there was no oxygen. After this point is reached in the mixtures, as the amount of carbon dioxide increased the amount of nitrates produced decreased. In the mixture containing 90 per cent of carbon dioxide there were no nitrates formed, but those present at the beginning were destroyed. This indicates that denitrification had set in with the mixtures containing a low percentage of oxygen. Bréal (1892) and others have observed that the denitrifiers show their effect when the oxygen supply is low.

In general these results show little difference from those obtained with the oxygen-nitrogen mixtures as long as there is a supply of oxygen present. So it seems to be of little consequence whether the oxygen is diluted with nitrogen or with carbon dioxide for the production of nitrates in soils.

TABLE 9

Composition of gas mixture added			Time of incubation (days)	Nitrates (NO_3) (parts per million dry soil)	Composition of gas mixture at end of experiment	
Carbon dioxide (per cent)	Oxygen (per cent)	Nitrogen (per cent)			Oxygen (per cent)	Carbon dioxide (per cent)
0.8	94.8	5.0	14	250.0	83.3	9.0
0.8	94.8	5.0	28	277.0	77.7	12.6
2.0	93.0	5.0	14	286.0	79.0	12.0
2.0	93.0	5.0	28	322.2	76.1	14.6
4.0	91.0	5.0	14	295.5	75.6	14.4
4.0	91.0	5.0	28	377.7	70.9	18.6
9.6	85.4	5.0	14	317.8	70.6	20.1
9.6	85.4	5.0	28	499.0	64.3	24.2
15.0	80.0	5.0	14	349.9	64.7	25.2
15.0	80.0	5.0	28	533.0	51.8	29.8
20.0	75.0	5.0	14	328.3	62.5	26.8
20.0	75.0	5.0	28	644.5	53.0	33.3
25.0	70.0	5.0	14	347.5	55.4	33.1
25.0	70.0	5.0	28	693.1	47.5	38.9
31.0	64.0	5.0	14	371.9	48.3	39.5
31.0	64.0	5.0	28	693.1	36.3	44.0
41.0	54.0	5.0	14	537.0	29.9	54.7
41.0	54.0	5.0	28	763.4	23.6	57.8
45.0	50.0	5.0	14	539.5	24.8	58.4
45.0	50.0	5.0	28	798.4	16.9	61.9
51.0	44.0	5.0	14	596.4	17.5	64.6
51.0	44.0	5.0	28	846.7	9.4	67.2
60.0	35.0	5.0	14	671.1	2.9	75.8
60.0	35.0	5.0	28	896.5	None	80.0
65.0	30.0	5.0	14	511.1	4.7	67.2
65.0	30.0	5.0	28	624.8	None	79.6
75.0	20.0	5.0	14	485.8	2.0	81.0
75.0	20.0	5.0	28	405.1	None	85.2
80.0	15.0	5.0	14	337.9	1.4	87.9
80.0	15.0	5.0	28	299.1	None	86.3
90.0	5.0	5.0	14	—36.5*	None	93.9
90.0	5.0	5.0	28	—30.1	None	94.1
93.0	2.0	5.0	14	—29.4	None	96.1
93.0	2.0	5.0	28	—36.5	None	95.6
99.0	....	....	14	—36.5	None	98.8
99.0	....	....	28	—36.5	None	99.2

*Minus sign denotes that there were less nitrates than at the beginning of the experiment.

Effect of mixtures of carbon dioxide, oxygen, and nitrogen on nitrification

Since the soil air is made up of various concentrations of oxygen, nitrogen, and carbon dioxide, varying mixtures of these gases were used in further study. The results are given in table 10.

TABLE 10

Composition of gas mixture added			Time of incubation (days)	Nitrates (NO_3) (parts per million dry soil)	Composition of gas mixture at end of experiment	
Carbon dioxide (per cent)	Oxygen (per cent)	Nitrogen (per cent)			Oxygen (per cent)	Carbon dioxide (per cent)
0.5	20.9	78.7	14	382.4	1.0	11.2
0.5	20.9	78.7	28	452.1	None	13.8
1.0	20.8	78.7	14	423.7	1.2	12.5
1.0	20.8	78.7	28	480.0	None	14.9
2.5	20.5	77.0	14	423.7	1.0	14.2
2.5	20.5	77.0	28	547.0	None	16.7
5.0	20.0	75.0	14	366.5	0.9	15.4
5.0	20.0	75.0	28	478.7	None	19.4
8.0	19.3	72.7	14	340.1	0.6	17.7
8.0	19.3	72.7	28	374.1	None	24.0
10.0	19.0	71.0	14	315.3	0.6	17.7
10.0	19.0	71.0	28	372.8	None	19.7
15.0	17.9	67.1	14	304.4	0.5	21.0
15.0	17.9	67.1	28	337.9	None	24.0
20.0	16.8	63.6	14	282.2	0.1	26.0
20.0	16.8	63.6	28	324.4	None	26.8
30.0	14.7	55.3	14	210.0	0.2	33.8
30.0	14.7	55.3	28	310.7	None	36.8
35.0	13.4	51.1	14	174.0	None	38.8
35.0	13.4	51.1	28	240.6	None	39.8
44.0	11.8	45.0	14	163.3	None	47.7
44.0	11.8	45.0	28	86.1	None	46.5
49.0	10.7	40.3	14	166.6	None	47.7
49.0	10.7	40.3	28	70.2	None	46.5
55.0	9.5	35.3	14	9.2	None	58.8
55.0	9.5	35.3	28	—8.3*	None	63.1
60.0	8.4	31.6	14	10.3	None	63.9
60.0	8.4	31.6	28	—8.6	None	68.7
69.0	6.5	24.3	14	—5.5	None	74.6
69.0	6.5	24.3	28	—9.9	None	75.2
77.0	4.6	18.4	14	—7.6	None	82.1
77.0	4.6	18.4	28	—8.8	None	81.1
86.0	2.9	11.1	14	—14.3	None	88.3
86.0	2.9	11.1	28	—9.1	None	88.6
98.0	0.4	1.6	14	—22.3	None	98.6
98.0	0.4	1.6	28	—22.3	None	98.7

*Minus sign denotes that there were less nitrates than at the beginning of the experiment.

The lower concentrations of carbon dioxide seem to have little effect on nitrification as shown in table 10. Increasing the amount of carbon dioxide above 30 per cent causes a noticeable reduction in nitrates formed. So long as the oxygen supply is about the same, the variations are slight, giving further evidence that oxygen is necessary to promote nitrification in soils. After the 30-per-cent limit of carbon dioxide is passed, no oxygen is found in the gas mixtures even after fourteen days of incubation. A steady decrease in nitrates is also noted beyond this limit, and when 44 per cent of carbon dioxide is reached there are less nitrates at the end of twenty-eight days than were found at fourteen days. Beyond 60 per cent of carbon dioxide denitrification occurred in all cases. Tho the nitrates were destroyed, none of the oxygen was liberated in the elementary form, for in no case was any oxygen found in the gas mixtures.

In Owen's (1908) work, in which nitrate tests were supposed to be conducted in an excess of carbon dioxide, there really was an atmosphere entirely composed of this gas. To find no increase in nitrate formation under such conditions is exactly what is to be expected.

Denitrification occurred where there was a limited supply of oxygen, and it was thought to be of interest to get further data as to the extent to which nitrates were destroyed by the denitrifying bacteria. In this experiment eight flasks were set up as usual, with ordinary air instead of gas mixtures. Two of these flasks were analyzed at the end of fourteen days, two at the end of twenty-eight days, and the remaining four at the end of fifty-six days. The results are given in table 11:

TABLE 11

Composition of gas mixture added		Time of incubation (days)	Nitrates (NO_3) (parts per million dry soil)	Composition of gas mixture at end of experiment	
Oxygen (per cent)	Nitrogen (per cent)			Oxygen (per cent)	Carbon dioxide (per cent)
21	79	14	290.8	2.7	10.2
21	79	14	308.8	2.1	11.0
21	79	28	353.9	None	11.9
21	79	28	353.9	None	11.8
21	79	56	—19.6*	None	17.3
21	79	56	—18.4	None	18.8
21	79	56	—18.6	None	19.0
21	79	56	—20.7	None	19.0
Nitrates at beginning			23.1		
Nitrates at beginning			23.1		

*Minus sign denotes that there were less nitrates than at the beginning of the experiment.

The results show clearly that the bacteria themselves can produce conditions favorable for denitrification. The percentage of oxygen found in the flasks that were analyzed at the end of fourteen days was only 2.4. At the end of twenty-eight days there was no oxygen, but the nitrates were somewhat higher than at fourteen days. In the flasks that were incubated for fifty-six days there were found less nitrates than the soil contained at the beginning of the experiment. This is in agreement with the work of Dehérain (1897), who found that denitrification was an extremely rapid process when the conditions were favorable to the denitrifying bacteria. Lemmermann, Fischer, Kappen, and Blanck (1909) observed that lime increases the action of the denitrifiers. The conditions were therefore favorable for this process in this experiment. Here again none of the oxygen that was consumed in the production of nitrates was found in the elementary form.

RELATION OF OXYGEN AND CARBON DIOXIDE TO AMMONIFICATION IN SOILS

Method of investigation

Casein was chosen as the substance to furnish the ammonifiable nitrogen, and its solution in sodium hydroxide was made according to the directions given by Brown (1913). Moisture was determined at the beginning of each experiment and 100 grams of fresh soil was placed on a large glass plate. Ten cubic centimeters of the casein solution, with enough water added to bring the water content to 25 per cent (dry basis), was intimately mixed with the soil. This was then placed in the flasks (500-cubic-centimeter Erlenmeyer) and exposed to the various gas mixtures for three days at a temperature of 30° C. At the end of three days the flasks were removed and 400 cubic centimeters of water, containing 4 cubic centimeters of concentrated hydrochloric acid, was added. This was stirred for five minutes and allowed to set for twenty minutes, and the whole was then thrown on an ordinary filter. Three hundred cubic centimeters of the filtrate was distilled with magnesium oxide, the distillate being caught in fifth-normal hydrochloric acid and titrated in the usual manner.

It was found that there was practically no difference between the results obtained with varying mixtures of oxygen and nitrogen, as will be shown later. Since it was possible that the ammonia was produced in the distillation process, experiments were set up to test this point. A comparison of the different methods of distillation was also made — that is, distillation of the soil directly with magnesium oxide by the use of steam, and extraction with weak hydrochloric acid. This was done as follows: To eight 100-gram portions of fresh soil 10 cubic centimeters of casein solution was added. Four of these portions were extracted with dilute hydrochloric acid and the filtrate was distilled with magnesium oxide, as usual. The other four were washed into the distillation flasks, magnesium oxide was added, and the distillation was made with steam. The results of this experiment are given in table 12:

TABLE 12

Extraction with hydrochloric acid		Distillation with steam	
Flask no.	Milligrams of ammonia nitrogen per 100 grams of soil	Flask no.	Milligrams of ammonia nitrogen per 100 grams of soil
1	0.39	1	1.12
2	0.56	2	0.84
3	0.93	3	0.84
4	0.56	4	0.64
Average	0.61	Average	0.86

These results show that the ammonia produced is not developed in the process of distillation. As the extraction method showed slightly lower results than distilling the soil directly, it was decided to continue its use.

It was thought probable that nitrification had taken place to some extent during the three days of incubation. Stevens and Withers (1910 b) and others have found that even excessive quantities of organic matter do not inhibit nitrification in soils.

In order to determine nitrates in the presence of excessive quantities of organic matter, it is necessary to use some other than the phenol-disulfonic-acid method, it being generally recognized that this method is not reliable in such cases. Burgess (1913) showed that the aluminum reduction method may be satisfactorily applied to soils containing alkali salts. It appears that this method is applicable for the determination of nitrates in the presence of organic material. It is in common use for such determination with sewage waters, in which the organic content is high.

Ammonia and nitrate determinations could not be made on the same sample. It was therefore necessary to set up four flasks, in two of which ammonia was determined by the extraction method while the other two were analyzed for nitrates by the aluminum reduction method.

Effect of mixtures of oxygen and nitrogen on ammonification

The averages of three experiments with the same gas mixtures are given in table 13.

Except in the case of 95-per-cent oxygen there is little difference in the amounts of ammonia formed. This result is rather unexpected, since the various oxygen-nitrogen mixtures produce decidedly different effects on nitrification. The analyses of the gases show clearly that oxygen has been consumed with the rapid production of carbon dioxide. An interesting point brought out in this connection is the rapidity with which anaërobic conditions are produced, even with mixtures containing as much as 32 per cent of oxygen. Just why there should be so much less carbon dioxide found with the higher oxygen contents is not clear, unless there is less bacterial activity with these concentrations.

TABLE 13

Composition of gas mixture added		Milligrams of ammonia nitrogen per 100 grams of soil	Composition of gas mixture at end of experiment	
Oxygen (per cent)	Nitrogen (per cent)		Oxygen (per cent)	Carbon dioxide (per cent)
21	79	21.0	None	16.3
32	68	18.8	None	26.5
40	60	19.9	3.2	28.2
50	50	18.6	7.1	34.5
75	25	16.2	33.3	22.6
95	5	10.2	73.5	20.7

Experiments were set up to ascertain whether nitrification had taken place in the flasks. The averages of three experiments to test this point are given in table 14:[3]

TABLE 14

Composition of gas mixture added		Milligrams of nitrogen as NH_3 per 100 grams of soil	Milligrams of nitrogen as NO_3 per 100 grams of soil	Total milligrams of nitrogen ammonified per 100 grams of soil
Oxygen (per cent)	Nitrogen (per cent)			
21	79	16.4	2.8	19.2
30	70	17.6	3.3	20.9
40	60	17.5	4.2	21.7
50	50	17.7	4.6	22.3
60	40	17.5	4.2	21.7
80	20	16.6	3.0	19.6
90	10	14.5	2.6	17.1
95	5	11.4	1.9	13.3

The table shows that nitrification does take place in the flasks even tho the period of incubation is short. Whether this nitrification is as great as is represented by the analyses the writer will not attempt to say. Qualitative tests by the diphenylamine reaction show that there are considerably more nitrates present after incubation than when incubation was begun. Nitrates were determined by the phenol-disulfonic-acid method at the beginning of each experiment and the amount found was deducted from the amount found by the reduction method at the end, giving the figures shown in the table. There is a rather close agreement in the rise of nitrate nitrogen with that produced in the nitrification studies (table 4). The results from both experiments show the maximum amount with mixtures containing from 40 to 50 per cent of oxygen.

---

[3] The nitrate nitrogen reported in this table is the amount formed during incubation.

The nitrogen occurring as ammonia is nearly the same in all cases, except with the pure oxygen. Including the pure oxygen, there is a difference of only six milligrams between the least and the greatest amount produced. When the total nitrogen ammonified (nitrate nitrogen plus ammonia nitrogen) is taken into account the difference is greater, being in this case 9 milligrams. This indicates a tendency toward equilibrium between the nitrifiers and the ammonifiers. Assuming that nitrates must pass through the ammonia stage, the total ammonia produced is increased by a supply of oxygen. The mixtures containing from 30 to 80 per cent of oxygen give consistently higher results than does ordinary air. The basic condition of the soil used in these experiments tended to increase the activities of all bacteria operating in the flasks.

Effect of mixtures of oxygen and carbon dioxide on ammonification

The mixtures used in the experiments to determine the effect of oxygen and carbon dioxide on ammonification were made as in the nitrification experiments (page 319). The averages of the results are given in table 15:

TABLE 15

Composition of gas mixture added			Time of incubation (days)	Milligrams of nitrogen as NH_3 per 100 grams of soil	Milligrams of nitrogen as NO_3 per 100 grams of soil	Total milligrams of nitrogen ammonified per 100 grams of soil
Oxygen (per cent)	Nitrogen (per cent)	Carbon dioxide (per cent)				
21	79	. . .	3	18.6	2.0	20.6
21	79	. . .	3	18.6	2.2	20.8
40	. . .	60	3	18.0	3.8	21.8
40	. . .	60	3	18.6	3.2	21.8
60	. . .	40	3	18.4	3.6	22.0
60	. . .	40	3	18.1	3.6	21.7
70	. . .	30	3	17.2	3.0	20.2
70	. . .	30	3	16.8	2.8	19.6
90	. . .	10	3	12.8	2.0	14.8
90	. . .	10	3	13.0	1.8	14.8

While there are little differences in ammonia nitrogen between the various gas mixtures shown in the above table, there is a slight increase in nitric nitrogen with the mixtures containing from 40 to 60 per cent of oxygen. This was found to be the case also with the oxygen-nitrogen mixtures. It would seem, therefore, to be of small consequence whether the oxygen is diluted with carbon dioxide or with nitrogen, so long as there is a liberal supply present.

Effect of mixtures of carbon dioxide, oxygen, and nitrogen on ammonification

The results of the experiment to determine the effect of various mixtures of carbon dioxide, oxygen, and nitrogen on ammonification are given in table 16:

TABLE 16

Composition of gas mixture added			Milligrams of nitrogen as NH_3 per 100 grams of soil	Milligrams of nitrogen as NO_3 per 100 grams of soil	Total milligrams of nitrogen ammonified per 100 grams of soil
Carbon dioxide (per cent)	Oxygen (per cent)	Nitrogen (per cent)			
10.0	18.9	71.1	17.5	5.9	23.4
20.0	16.8	63.2	16.9	5.9	22.8
40.0	12.6	47.4	17.0	4.4	21.4
60.0	8.4	31.6	16.4	4.2	20.6
80.0	4.2	15.8	13.8	1.5	15.3
99.0	....	....	9.8	0.3	10.1

Here again nitrification appears plainly. Tho the differences are small until the higher concentrations of carbon dioxide are reached, they are perceptible. The lowering of the amount of ammonia produced in the presence of high concentrations of carbon dioxide is noteworthy. That any appreciable quantity of ammonia is formed under strictly anaërobic conditions is in line with the work of Kelley (1911) on the inundated soils of Hawaii. In general the results are in agreement with those already shown. There are less ammonia and nitrates formed when the carbon dioxide is highest and the oxygen lowest. This necessity for oxygen is indicated also in the results from the mixtures of carbon dioxide and nitrogen (table 8).

SUMMARY

Altho the methods used in this investigation are not so suitable as might be desired, the following conclusions seem to be justified from the results obtained:

1. Vigorous nitrification takes place in sealed flasks as long as there is a supply of oxygen.

2. Of the soil gases studied, oxygen is the limiting constituent, and there is an optimum mixture of this gas (one containing from 35 to 60 per cent of oxygen) for nitrification.

3. From the losses of oxygen from the gas mixtures it seems certain that there are other forms of oxidation than that caused by the nitrate bacteria.

4. A large quantity of carbon dioxide is produced when lime is used, amounting in some instances to nearly 20 per cent. The greatest production of this gas accompanies the point of maximum nitrification. Ammonium sulfate, when applied to this soil without the addition of lime, produces only slight increases in nitrification even after incubation for a period of twenty-eight days. The small quantity of carbon dioxide formed under such conditions would tend to indicate that ammonium sulfate, when applied to this soil alone, depresses the action of the carbon-dioxide-producing bacteria as well.

5. Taking the results as a whole it cannot be said that carbon dioxide has any material effect on nitrification so long as oxygen is present in the atmosphere. It is of little consequence whether the oxygen is diluted with the inert gas nitrogen or with carbon dioxide. When the supply of oxygen becomes limited and anaërobic conditions are produced, denitrification sets in, and this continues until practically all the nitrates are destroyed. In no case with these experiments was the combined oxygen liberated in the elementary form during the processes of denitrification.

6. The results with the distillation method for the determination of ammonia show that there is no optimum content of oxygen for the production of this compound. The results of all mixtures, except the very high concentrations of oxygen, are practically the same. It seems to make little difference whether the mixtures are made with oxygen and nitrogen or with oxygen and carbon dioxide. Under purely anaërobic conditions, caused by an atmosphere of pure carbon dioxide, there is somewhat less ammonia produced than when oxygen is present at the beginning. That ammonia is formed in rather large quantities under such conditions is noteworthy.

7. Nitrate determinations show that nitrates are produced in ammonification tests even tho the organic content is high and the period of incubation is short.

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DUSTING AND SPRAYING NURSERY STOCK

VERN B. STEWART

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DUSTING AND SPRAYING NURSERY STOCK

Vern B. Stewart

During the season of 1915 several experiments were conducted by the Department of Plant Pathology at Cornell University for the control of various leaf diseases of nursery stock.[1] The results obtained seemed to warrant further trials, and in 1916 the experimental work was continued on a more extensive scale. For the experiments in 1916 traction dusting machines (figs. 71 and 72) were used for applying the dust mixture, instead of the hand machine employed in 1915 (fig. 73). In most cases a half acre or more of stock was treated in order to thoroughly test the efficiency of the dust method. The dust mixture used for all experiments in 1916 was the same as that employed in 1915, namely, ninety parts of finely ground sulfur and ten parts of powdered arsenate of lead.[2]

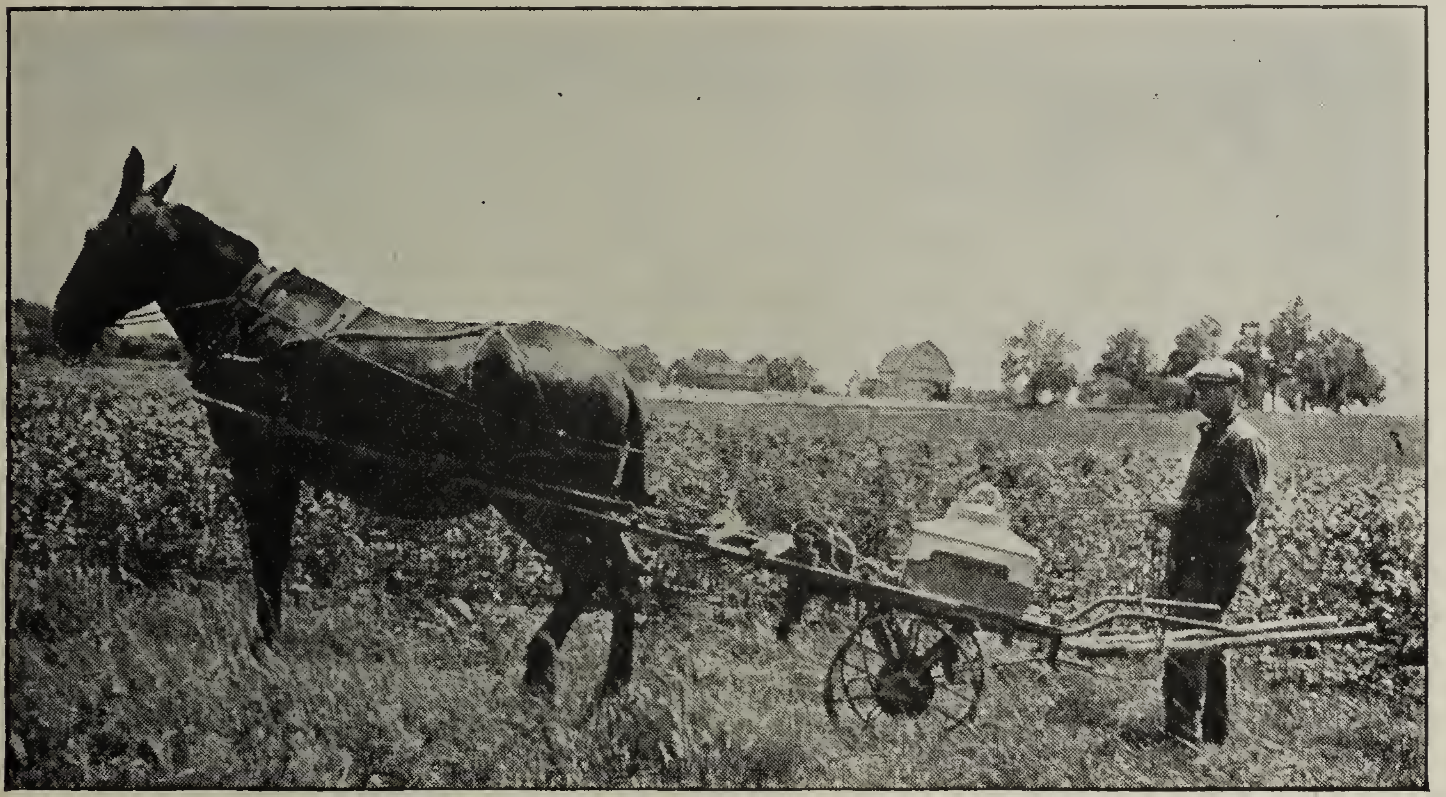

Fig. 71. A TRACTION DUSTER

The hopper of this machine holds about fifty pounds of dust mixture, which is discharged from the pipes in the rear. Photograph by R. E. Matheson

In each experiment one or more small plats were treated with lime-sulfur solution to serve as a comparison with the dusted and the untreated plats. The lack of suitable spraying machinery made it necessary to apply the spray solution with a compressed-air hand sprayer; this was somewhat disadvantageous, since the pressure obtained with the hand sprayer was considerably less than that furnished by a traction or a power sprayer. Also it was necessary to limit the sprayed plats to a much smaller area than the dusted plats. On the other hand, in practically all cases the sprayed plats were large enough to determine the relative value of the dusting and the spraying method.

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[1] Stewart, V. B. Dusting nursery stock for the control of leaf diseases. Cornell Univ. Agr. Exp. Sta. Cir. 32:3–10. 1916.

[2] In all the experiments a finely ground flour sulfur, now known commercially as superfine sulfur, was used. This product is ground to such a fineness that at least 95 per cent will pass through a screen of 200 meshes to the inch. The arsenate of lead used was of the so-called fluffy type, the individual particles of which are much smaller than the majority of the particles of sulfur.

WEATHER CONDITIONS

Although the seasons of 1915 and 1916 were both exceptionally favorable for leaf diseases, there was considerable difference with respect to the occurrence of the various rainy periods.

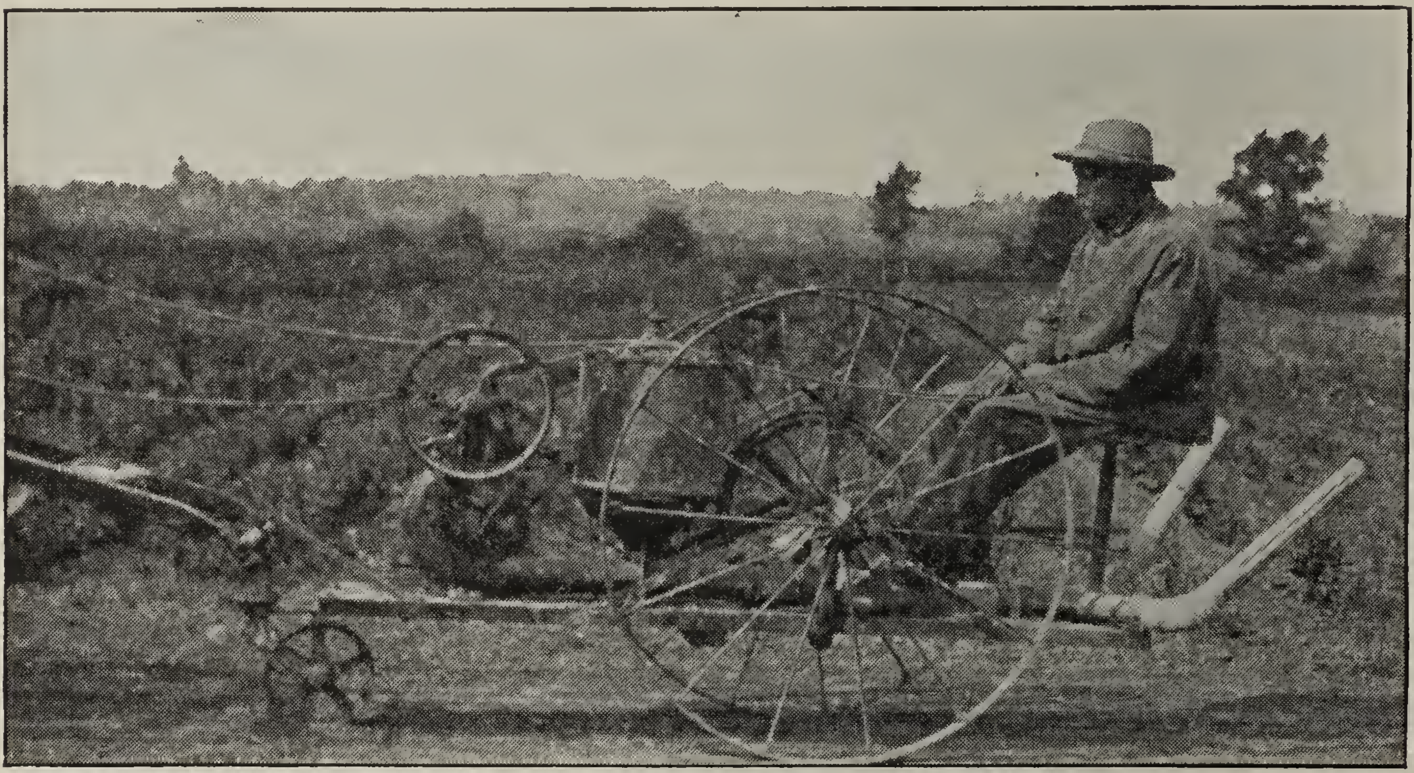

Fig. 72. A TRACTION DUSTING MACHINE

This machine is twenty-eight inches wide. The discharge pipes in the rear can be raised and lowered according to the height of the nursery stock. Large nursery trees, seven or more feet in height, can be thoroughly dusted. Photograph by C. R. Crosby

In 1915 there was very little precipitation previous to July 1 and the primary infection early in the spring was of little importance. Most foliage was relatively free from disease until after the prolonged infection period from June 30 to July 6. For the remainder of the summer, conditions were exceptionally favorable for leaf diseases and they appeared in great abundance.

In 1916 early infections were unusually severe owing to the excessive amount of precipitation accompanied by prolonged periods of damp, cloudy weather. During May and June leaf diseases appeared in great abundance and proved very destructive to all kinds of stock affected. Some plants suffered almost complete defoliation as early as July 1. After July 1 there was practically no rainfall until August 11 and 12, when an infection occurred which caused considerable loss of foliage. In some cases the effect of the defoliation in midsummer was very severe. The growth of the plants was completely checked until after the rainfall late in August, when the precipitation prompted a new growth and many of the plants developed clusters of small new leaves at the tips of the shoots. This late growth delayed proper maturation of the plants in the autumn and made them more susceptible to winter injury.

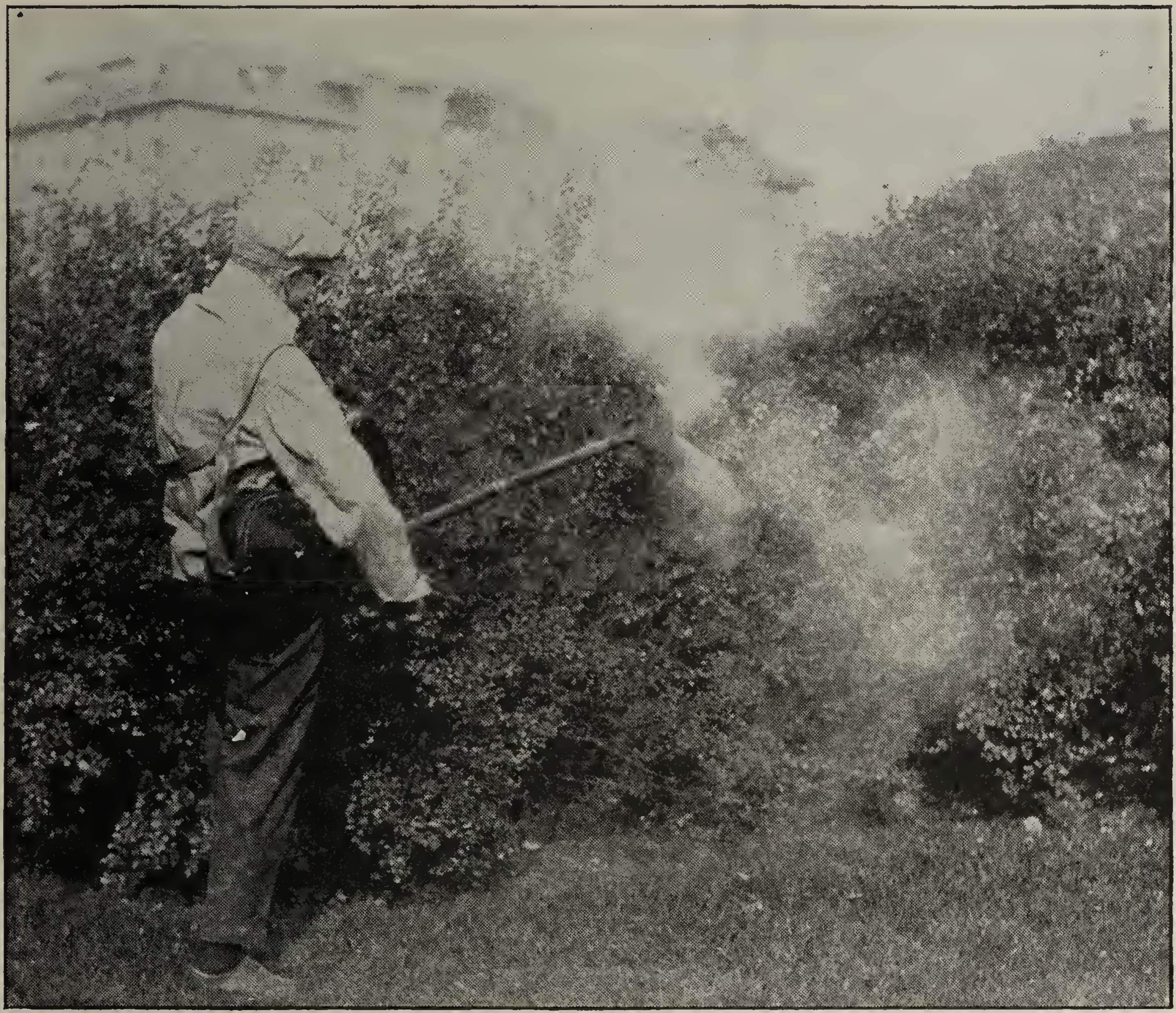

FIG. 73. A HAND DUSTING MACHINE
This machine is suitable for treating small plantings of nursery stock

ARRANGEMENT OF EXPERIMENTAL PLATS

Since a complete report of the results obtained in 1915 has not been recorded, a somewhat detailed account is included in this publication of experiments for both 1915 and 1916.

The location of the experimental plats frequently has an important bearing on the results. There is always danger that the dust mixture may be carried by the wind to the other plats, and this difficulty makes it impossible to select trees in adjoining rows for different kinds of treatment when a dust mixture is used. For most of the experiments performed, the plats were arranged so that a part of each row of plants was included in each of the different plats. With such an arrangement there is less danger that the dust mixture may affect the results in the sprayed and the untreated plats. On the other hand, this plan is objectionable since there may be a lack of uniformity in the plats with respect to soil conditions and other factors that influence the growth of the plants. Often trees in the same row show a marked difference in size. These conditions make it impossible to compare the experimental plats by determining the caliper and height measurements of the individual plants. Therefore, since the growth of nursery stock is seriously affected by the loss of foliage during the growing season, the amount of premature defoliation was the principal factor considered in determining the damage caused by the leaf diseases. The loss of foliage tends to check the growth of the plant, and thus influences the caliper and height measurements.

Experiments were performed for the control of leaf diseases of horse-chestnut, currant, plum, cherry, quince, apple, and rose.

LEAF BLOTCH OF HORSE-CHESTNUT[3]

In 1915 a single row of large four-years-old horse-chestnut trees was selected for the experiment on leaf blotch, and the same trees were again used for an experiment in 1916. In both seasons the trees in the first 150 feet of the row were treated with the dust mixture; those in the next 50 feet were left untreated; those in the next 100 feet were sprayed with lime-sulfur solution; and those in the last 75 feet were left untreated.

Experiment in 1915

In 1915 the first application of dust and spray was made on May 11, when all the buds had opened and some of the leaves were well developed. Subsequent applications were made on May 25, June 7, June 21, July 9, and August 2. Lime-sulfur solution diluted one to fifty was used for treating the sprayed plat. In the attempt to thoroughly cover all parts of the foliage by means of a hand sprayer, many of the leaves were drenched with the spray liquid and considerable injury resulted.

A comparison of the trees in the different plats was obtained by determining the percentage of affected leaflets on each tree. Many leaf pathogenes cause severe defoliation, but usually most of the horse-chestnut leaves affected with the leaf blotch disease remain on the tree. However, on smaller trees, especially seedlings, considerable defoliation may occur. When severely affected the foliage has the appearance of having been burned over by fire.

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[3] The leaf blotch disease of horse-chestnut is caused by the fungus *Guignardia Æsculi* (Peck) Stewart.

The number of trees of which records were taken, the total number of leaflets, and the number and mean percentage of infected leaflets for the trees in the different plats, are shown in table 1. Approximately sixty per cent of the foliage on the untreated trees showed infections of the leaf blotch disease, while only three per cent of the foliage was diseased on the dusted trees. The dense foliage on the trees hindered the proper distribution of the lime-sulfur spray over all the leaves, and this, no doubt, reduced somewhat the effectiveness of the spray solution. About twelve per cent of the foliage on the sprayed trees was diseased.

TABLE 1. DUSTING AND SPRAYING EXPERIMENT WITH HORSE-CHESTNUT TREES IN 1915

Treatment	Number of trees	Total number of leaflets	Affected leaflets	
			Number	Mean percentage
Untreated	55	7,980	4,737	59.08 ± 2.61
Lime-sulfur solution 1 to 50	61	7,385	762	11.78 ± 0.95
Sulfur 90, arsenate of lead 10	72	9,735	310	3.11 ± 0.20

Experiment in 1916

The experiment for the control of leaf blotch of horse-chestnut was repeated in 1916, using the same row of trees as in 1915. Owing to the foliage injury caused by the lime-sulfur solution the previous year, the solution used in 1916 was diluted one gallon to sixty gallons of water.

The first application was made in the forenoon of May 15, between showers of a rain period which began in the afternoon of May 14 and continued until May 17. At this time most of the leaves on the trees were about two-thirds developed and during the rainy weather a severe ascospore infection occurred. Other applications were made on May 29, June 13, July 5, and July 25. When final observations were made on September 11, the untreated trees had the appearance of having been burned over by fire, practically all the leaves being affected. Considerable disease was also apparent on the sprayed trees.

The results of the experiment are given in tables 2 and 3.[4] Approximately ninety-nine per cent of the untreated foliage was diseased as

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[4] Complete data of the records taken in the untreated and in the dusted horse-chestnut plats for the experiment conducted in 1916 are given in table 2. The total number of leaflets for each tree was recorded, along with the number of diseased leaflets, and from these figures the percentage of infected leaflets for each tree was determined. The percentage column shows the variation in amount of diseased leaflets

TABLE 2. COMPLETE DATA OF RECORDS FOR UNTREATED AND DUSTED HORSE-CHESTNUT TREES FOR EXPERIMENT IN 1916

Treatment	Total number of leaflets	Affected leaflets		Treatment	Total number of leaflets	Affected leaflets	
		Number	Percentage			Number	Per-centage
Untreated	440	440	100.00	Sulphur 90, arsenate of lead 10	185	10	5.40
	255	250	98.04		350	35	10.00
	205	205	100.00		475	100	21.05
	475	475	100.00		260	28	10.77
	400	400	100.00		645	30	4.65
	260	260	100.00		110	15	13.64
	630	624	99.05		570	25	4.38
	480	480	100.00		275	30	10.91
	610	593	97.21		700	40	5.71
	30	30	100.00		390	15	3.85
	355	355	100.00		300	42	14.00
	285	285	100.00		445	34	7.64
	450	448	99.55		475	39	8.21
	360	354	98.33		560	43	7.68
	425	418	98.35		280	24	8.57
	505	505	100.00		215	29	13.49
	180	172	95.55		480	40	8.33
	215	215	100.00		510	34	6.67
	375	365	97.33		310	41	13.22
	545	545	100.00		220	2	0.91
	525	525	100.00		360	32	8.89
					105	8	7.62
					240	22	9.17
					305	28	9.18
					440	36	8.18
Total	8,005	7,944	2,083.41	Total	9,205	782	222.12
Mean			99.21 ± 0.19	Mean			8.88 ± 0.50

compared with about nine per cent for the dusted trees. The failure of the lime-sulfur solution to protect the trees, which showed about fifty-five per cent of the leaves affected, is attributed in part to the use of a hand sprayer. It was difficult to thoroughly cover all of the dense foliage without drenching the leaves. Furthermore, diluting the lime-sulfur solution one to sixty reduced somewhat the fungicidal value of the spray solution. The relatively high percentage of diseased leaves on dusted trees, as compared to those dusted in 1915, is due chiefly to the infection that occurred during the night of May 14. There was a period of damp, cloudy weather of about eighteen hours duration before the first application was made. This apparently was sufficient time for the discharge of some of the ascospores of the fungus from the old leaves on the ground, and for these ascospores to produce infections on the new foliage before the fungicides were applied.

TABLE 3. DUSTING AND SPRAYING EXPERIMENT WITH HORSE-CHESTNUT TREES IN 1916

Treatment	Number of trees	Total number of leaflets	Affected leaflets	
			Number	Mean percentage
Untreated	21	8,005	7,944	99.21 ± 0.19
Lime-sulfur solution 1 to 60	25	9,375	5,212	54.61 ± 1.34
Sulfur 90, arsenate of lead 10	25	9,205	782	8.88 ± 0.50

The importance of the infection period of May 14 to May 17 is seen by the results of an experiment in another planting of horse-chestnut trees. Owing to the rainy weather it was necessary to delay the first application until May 26. During the prolonged period of infection from May 14 to May 17 before the trees were treated, a large percentage of the foliage became infected. The application made on May 26 was too late to prevent any of the primary infection, and since horse-chestnut

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for each tree. The probable error of the mean percentage was determined by means of Peter's formula, $\pm 0.8453 \frac{\Sigma v}{n\sqrt{n-1}}$, in which v equals the difference between the mean and the percentage of infected leaflets for each tree, and n equals the number of trees from which records were taken. In all the experiments the probable error of the mean percentage was determined by means of Peter's formula, except for the experiments with currants, in which case Bessel's formula, $\pm 0.6745 \sqrt{\frac{d^2}{n(n-1)}}$, was used. In this formula d is the difference between the mean and each individual observation, and n is the number of observations.

trees make but little secondary growth the experiment was abandoned. When observed on July 10 there was very little green foliage on any of the trees in the block. The failure to control the leaf blotch in these trees emphasizes the absolute necessity of making the applications before periods favorable for infection, so that the foliage may be protected. Otherwise such applications have little value.

The results of the experiments for the control of leaf blotch of horse-chestnut indicate that dusting is preferable to spraying. There is no question but that the lime-sulfur solution greatly reduced the amount of disease. On the other hand, it was not so effective as the dust mixture, and furthermore the spray liquid is more difficult to apply. In treating three- to five-years-old horse-chestnut trees in the nursery, the work can be done much better and more easily by means of the dusting method, at a cost which is little, if any, greater than that for the spraying method.

LEAF SPOTS OF CURRANT[5]

Experiment in 1915

The experiment performed in 1915 for the control of the leaf spots of currant included a number of rows, about 70 feet in length, of second-year Cherry currant bushes. Rows 1 to 6 were dusted; row 7 served as a buffer row and was not treated; rows 8, 9, 10, and 11 were sprayed with lime-sulfur solution diluted one to fifty; rows 12, 13, 14, 15, 16, and 17 were left untreated. The first application was made on May 10, soon after the leaf buds had opened. Subsequent applications were made on May 25, June 7, June 21, July 9, July 19, and August 2. Final data on the experiment were recorded on September 3, when a large part of the foliage on the untreated bushes had already fallen.

It is difficult to determine accurately the amount of damage caused by the leaf spots on currant bushes. A determination of the number of leaves infected is not a suitable method, since the presence of one or two small lesions on a leaf may not seriously affect it. On the other hand, if infection occurs on the petiole the leaf usually drops prematurely. Also many of the smaller leaves develop in a cluster, making it practically impossible to count the leaf scars of foliage missing and thus determine the number of leaves that were originally present on the bush. Since in each experiment the leaf spots caused severe premature defoliation in the untreated plats, comparisons were made of the bushes in the different plats by counting the number of leaves that remained on the bushes throughout the season. No insect pests were present and the amount of defoliation caused by agents other than the leaf spot fungi is considered negligible.

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[5] The leaf spot disease caused by *Mycosphærella grossulariæ* (Fr.) Lind., and the anthracnose caused by *Pseudopeziza ribis* Kleb., are commonly found on currant nursery stock in New York State.

The results of the experiment are given in table 4. The bushes in the different plats averaged about the same in size. However, as is to be noted in table 4 under *Remarks*, there was a great variation in number of leaves for individual bushes in each plat. There was very little premature defoliation of the bushes in the sprayed and the dusted plats. Most of the leaves remained on the bushes throughout the summer. At the end of the growing season there was an average of twenty-seven leaves per bush on the untreated bushes, as compared with an average of over eighty leaves on each bush in the treated plats.

TABLE 4. DUSTING AND SPRAYING EXPERIMENT WITH CURRANT BUSHES IN 1915

Treatment	Number of bushes	Total number of leaves	Average number of leaves per bush	Remarks
Untreated (Rows 14 and 15)	137	3,722	27.17 ± 1.36	Number of leaves per bush varied from 0 to 71
Lime-sulfur solution 1 to 50 (Row 9)	72	6,039	83.87 ± 4.04	Number of leaves per bush varied from 15 to 275
Sulfur 90, arsenate of lead 10 (Row 3)	74	6,328	85.51 ± 3.61	Number of leaves per bush varied from 4 to 183

Experiment in 1916

An experiment for the control of the leaf spots of currant was conducted in 1916, using a traction duster for applying the dust mixture. A number of rows of the White Grape variety in a block of currants were selected for the experiment. The rows were about 500 feet in length and extended north and south. Starting at the northeast corner, the bushes in the first 100 feet of twelve rows were sprayed with lime-sulfur solution 1 to 40; the bushes in the remaining 400 feet of nine of these rows on the east side were dusted with sulfur 90 parts and arsenate of lead 10 parts; eight rows extending the entire length of the block and adjoining the sprayed plat were left untreated for a check.

The first application was made on May 15, during an intermission in the rain period which lasted from May 14 until May 17. The first new leaves on the canes were about half developed when the bushes were treated. Apparently this application was made in time to prevent considerable primary infection, since there were but few infected leaves on the treated bushes when another application was made on May 29. The untreated bushes showed numerous diseased leaves on that date. Subsequent applications were made on June 13 and June 22, and then, because of the prolonged dry weather, the plats were not treated again until July 25. At that time the untreated bushes were almost completely defoliated, while very little of the foliage was missing from the dusted and the sprayed bushes. It would have been desirable to have made another application just previous to August 11, after which time there were several infection periods, but the delay in receiving repairs for a French dusting machine prevented further treatments for the season. When results of the experiment were recorded some of the leaves showed new leaf spot lesions, due to infections that occurred after August 11.

TABLE 5. SPRAYING AND DUSTING EXPERIMENT WITH CURRANT BUSHES IN 1916

Treatment	Number of bushes	Total number of leaves	Average number of leaves per bush	Remarks
Untreated	110	1,566	14.24 ± 0.95	Number of leaves per bush varied from 0 to 65
Lime-sulfur solution 1 to 40	56	5,393	96.30 ± 3.87	Number of leaves per bush varied from 7 to 171
Sulfur 90, arsenate of lead 10	56	5,656	101.00 ± 3.98	Number of leaves per bush varied from 21 to 242

As in the experiment in 1915, a comparison was obtained by counting the leaves present on individual bushes in the middle row of each plat. The average number of leaves on each bush in the dusted and the sprayed plats was approximately the same (table 5). Both fungicides were effective in preventing the attacks of the parasites which cause the leaf spot diseases. There was an average of about fourteen leaves on each bush in the untreated plat as compared with one hundred and one leaves on each bush in the dusted plat. The great variation in the number of leaves on each bush as indicated in table 5 is due to the differences in size of the individual bushes rather than to the results of premature defoliation.

LEAF SPOT OF PLUM[6]

There is a considerable difference in the susceptibility of the varieties of plum trees to the leaf spot, or shot-hole disease, which was unusually common in 1916. In the nursery the European varieties are severely affected and often complete defoliatoin of the trees occurs in midsummer. The Japanese varieties are not so susceptible (fig. 74). No experiments were performed for the control of this disease in 1915.

Experiment in 1916

Two rows of two-years-old European plum trees of the variety German Prune were selected for the experiment in 1916. The trees comprised the last two rows of a large block of plum trees of several varieties. Starting at the north end, the trees in the first 150 feet of the two rows were sprayed with lime-sulfur solution diluted one to fifty; those in the next 200 feet were left untreated; those in the next 500 feet were dusted with the 90–10 mixture of finely ground sulfur and powdered arsenate of lead; those in the last 300 feet were left untreated.

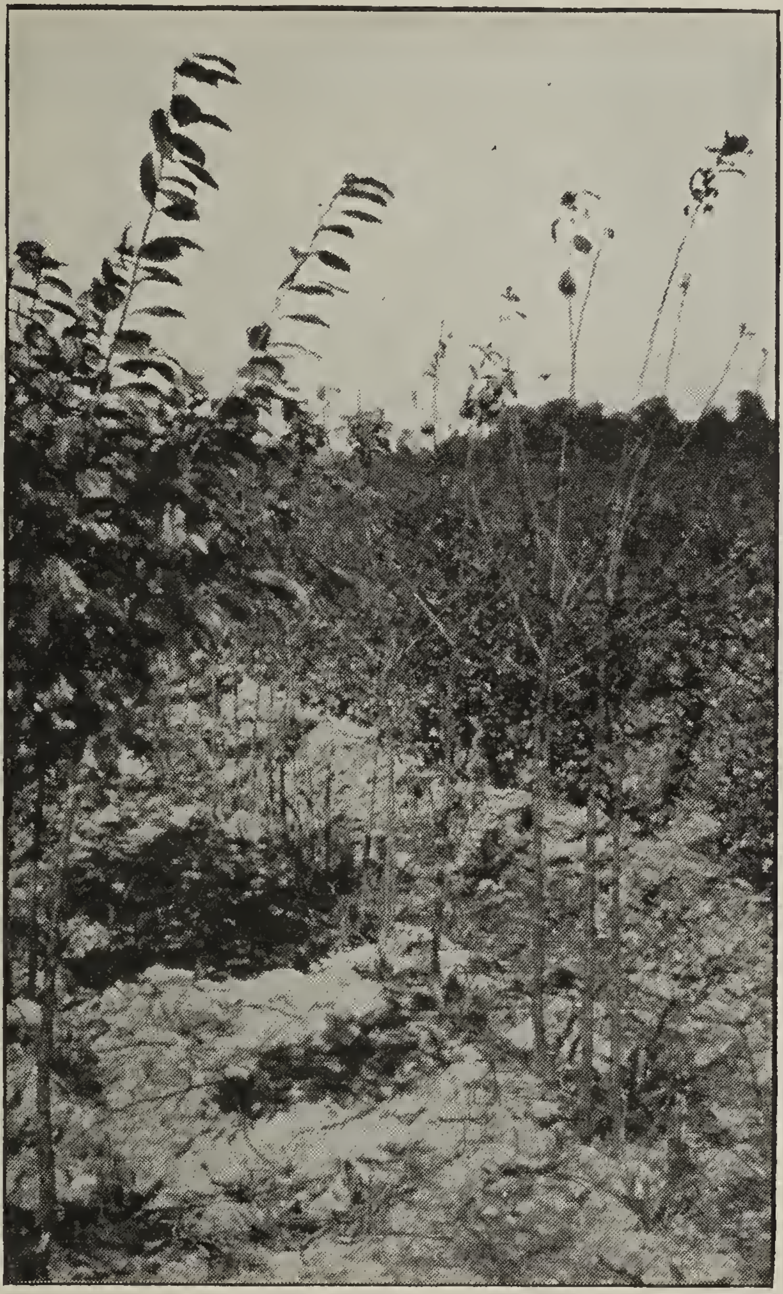

FIG. 74. VARIETAL SUSCEPTIBILITY OF PLUM TREES TO THE LEAF SPOT DISEASE

The trees on the right are of the European variety German Prune, and were defoliated by the leaf spot disease. The trees on the left are of the Japanese variety Wickson, and were not affected by the disease. Photographed September 14, 1916

The first application was made on May 26, when the first leaves were about half developed. The next three applications were made on June 12, June 23, and July 6. During this time there were numerous infection periods and on July 6 considerable leaf spot was present on the untreated trees. Subsequent applications were made on July 20 and August 9. On the latter date the untreated trees were practically defoliated and none of the leaves remaining on the trees were free from disease, while the sprayed and the dusted trees showed only a few infected leaves and almost no defoliation (fig. 75).

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[6] The plum leaf spot, or shot-hole disease, is caused by the fungus *Coccomyces prunophoræ* Higgins.

Final data on the experiment were recorded on September 14. Since on young branches of defoliated plum trees there is a well-defined scar where each leaf was attached, it was possible to count the number of leaf scars along with the leaves present and thereby estimate the number of leaves that were originally on the tree. The number of trees in each plat from which data were recorded, the estimated total number of leaves originally on the trees, the number of leaves present, and the number of leaves missing, are given in table 6. All records were taken from trees in the same row, and in each plat these trees were determined by selecting every fifth tree in the row. More than ninety-five per cent of the foliage remained on the treated trees throughout the season, as compared with less than twenty per cent on the untreated trees, which lost a large proportion of their leaves early in the summer.

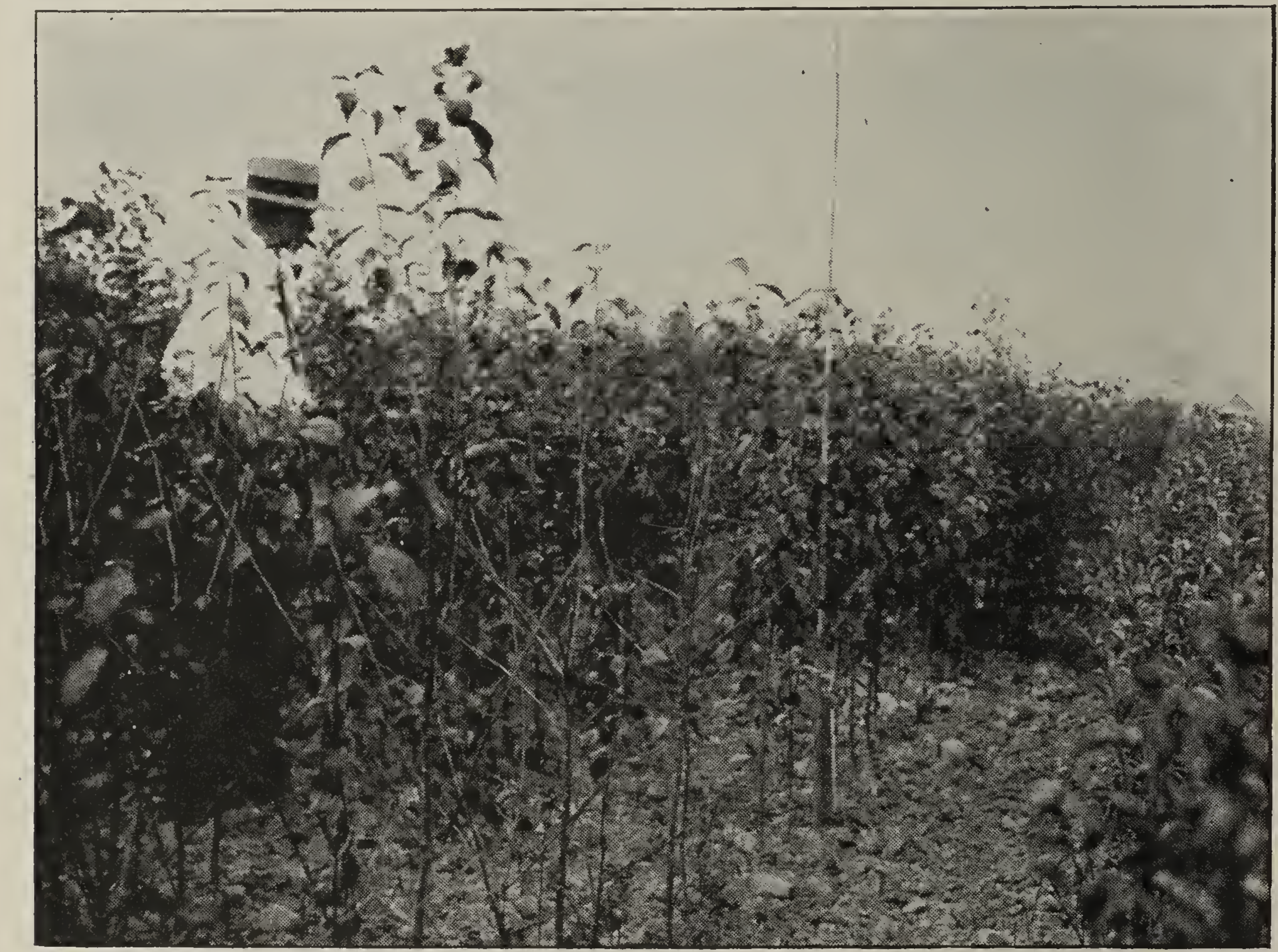

FIG. 75. DUSTED AND UNTREATED TWO-YEARS-OLD PLUM TREES OF THE VARIETY GERMAN PRUNE

The defoliated trees in the foreground were not treated; the trees in the distance were dusted and premature defoliation was prevented. Photograph by C. R. Crosby, August 9, 1916

On September 14 the untreated trees showed a larger percentage of non-infected foliage than when observed on August 9. This is accounted

TABLE 6. Dusting and Spraying Experiment with European Plum Trees in 1916

Treatment	Number of trees from which data were recorded	Total number of leaves originally on trees	Non-infected leaves present		Diseased leaves present		Leaves missing	
			Number	Mean percentage	Number	Mean percentage	Number	Mean percentage
Untreated	50	10,289	681	6.10 ± 0.74	1,015	10.40 ± 0.66	8,593	83.51 ± 0.95
Sulfur 90, arsenate of lead 10	45	7,234	6,856	94.72 ± 0.34	341	4.84 ± 0.31	37	0.45 ± 0.08
Lime-sulfur solution 1 to 50	45	7,235	6,940	95.85 ± 0.36	266	3.77 ± 0.31	29	0.37 ± 0.10

for by the fact that defoliation occurred early in the summer, and after the heavy rainfall in late August the trees began growing again. This late growth resulted in the development of new foliage, which in all cases was in the form of clusters of very small leaves at the tips of the shoots. Without question the development of the new leaves at this time was a detriment to the trees, since the late growth retarded proper maturation, making the trees more susceptible to winterkilling.

LEAF SPOT OF CHERRY[7]

Experiment in 1915

An experiment in 1915 for the control of leaf spot of cherry included four rows of first-year Tartarian cherry trees. The trees in the first 100 feet of the four rows were treated with the mixture of sulfur and powdered arsenate of lead; those in the next 125 feet were left untreated; those in the last 100 feet were sprayed with lime-sulfur solution diluted one to fifty. The first application of dust and spray was made on May 11, when the trees were about six inches high. Subsequent applications were made on May 25, June 7, June 27, July 9, July 19, and August 2.

TABLE 7. DUSTING AND SPRAYING EXPERIMENT WITH SWEET CHERRY TREES IN 1915

Treatment	Number of trees	Total number of leaves originally on trees	Leaves missing	
			Number	Mean percentage
Untreated	50	2,094	714	35.60 ± 0.94
Lime-sulfur solution 1 to 50	82	3,133	580	20.26 ± 0.77
Sulfur 90, arsenate of lead 10	84	3,539	292	9.64 ± 0.44

The young trees made a very rapid growth, and owing to the heavy rainfall and numerous infection periods it was difficult to make the applications so that the new foliage was protected at all times. Many infections occurred in all the plats, but the trees in the treated plats were not so severely infected as were the untreated trees.

The results of the experiment were recorded on August 31, all records being taken from trees in the third row, a part of which was in each of the different plats. The percentage of premature defoliation caused by the leaf spot disease was determined by counting the number of leaf scars on each tree where leaves were missing. The number of trees in each plat of which records were made is given in table 7, also the total number of leaves originally on the trees (determined by counting the leaves present plus the leaf scars due to defoliation), and the number and mean percentage of leaves missing.

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[7] The cherry leaf spot, or yellow-leaf disease, is caused by the fungus *Coccomyces hiemalis* Higgins.

In this experiment the lime-sulfur solution was not so effective as the dust mixture. This failure may be attributed, in part at least, to the location of the different plats. The sprayed trees were on lower land, where the soil remained saturated with water for a considerable length of time after periods of heavy rainfall. Not only did the excess of water affect the growth of the trees in that area, but also the moist conditions were more favorable for the leaf spot disease. This situation made a comparison of caliper and height measurements for trees in different plats of no value. Undoubtedly the defoliation would not have been so great on the sprayed trees if they had been in rows adjoining the dusted plat, which was on a gentle slope of land conducive to proper drainage.

Not only was there a higher proportion of premature defoliation on the untreated trees, but also the leaves that remained were more severely affected than those remaining on the treated trees, many of them turning yellow and being of little value to the trees. On the other hand, most of the foliage on the sprayed and the dusted trees showed only a few infections, and was still green when observed for the last time on September 11.

Experiment in 1916

Another experiment was conducted in 1916 for the control of the leaf spot disease of cherries, but unfortunately this experiment also failed to prove entirely satisfactory. The location of the different plats was again a factor influencing the results. The experiment as originally

TABLE 8. DUSTING EXPERIMENT WITH TWO-YEARS-OLD TARTARIAN CHERRY TREES IN 1916

Treatment	Number of trees	Total number of leaves originally on trees	Leaves missing	
			Number	Mean percentage
Untreated	20	2,629	1,801	68.23 ± 1.48
Sulfur 90, arsenate of lead 10	19	2,818	478	16.77 ± 0.60

planned consisted of seven rows of two-years-old Tartarian cherry trees. There were five experimental plats, so arranged that a part of each row of trees was included in each plat. Poor drainage, along with injury by freezing which had occurred during the winter months, affected the growth of the trees to such an extent that early in the summer the experiment, except for one dusted plat and an adjoining untreated plat, was abandoned.

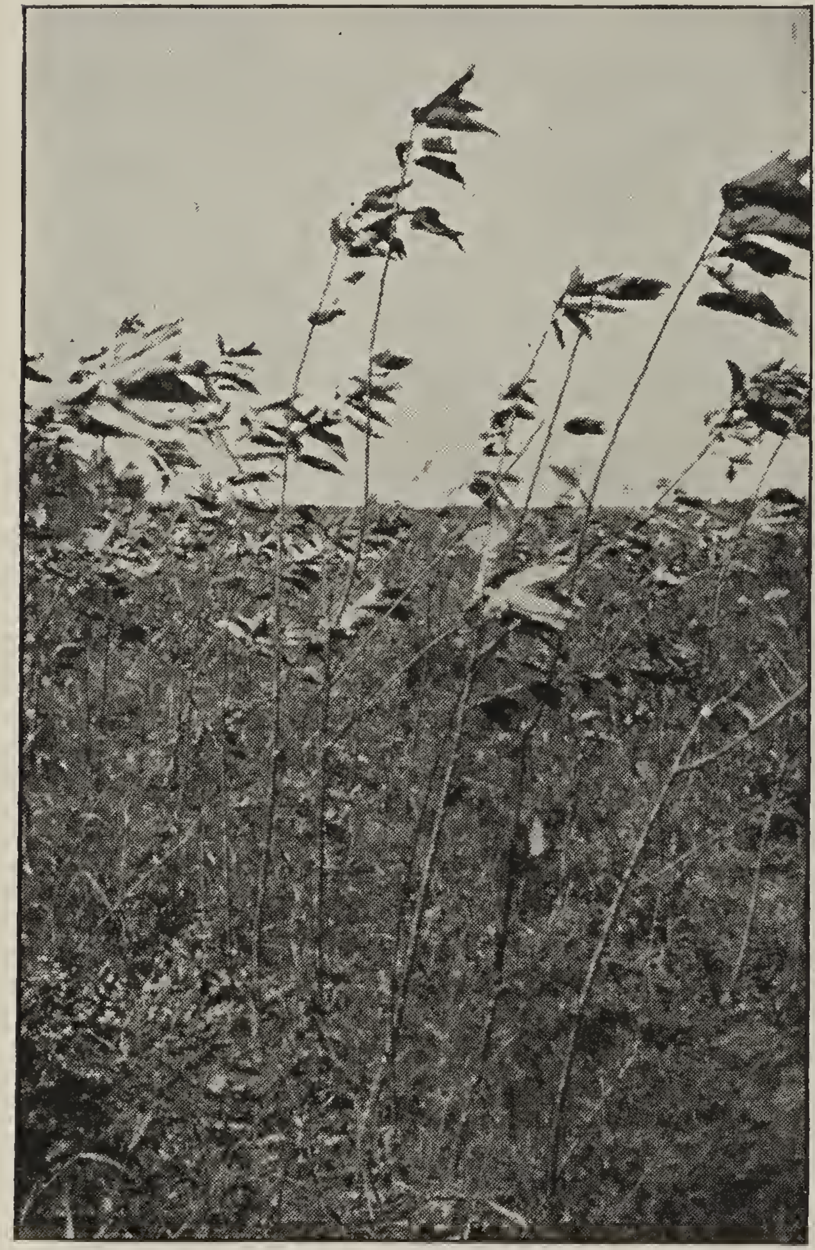

FIG. 76. TWO-YEARS-OLD SWEET CHERRY TREES DEFOLIATED BY THE LEAF SPOT DISEASE

Many of these trees failed to make sufficient growth to be graded as first-class stock. Photographed September 11, 1916

The first application was made on May 15, when the first leaves were about one-third developed. Subsequent applications were made on May 29, June 13, June 22, July 5, and July 25. On June 10 a heavy precipitation occurred, followed by damp, cloudy weather for a period of twenty-four hours. At this time the trees were growing very rapidly and had made considerable new growth since the last treatment on May 29. The weather conditions of June 10 and 11 were favorable for the leaf spot disease, and many infections occurred on the new unprotected foliage in both plats. No treatments were made after July 25, owing to the delay in receiving repairs for the French dusting machine which was in use at this nursery.

When final data on this experiment were recorded (table 8), lesions of the leaf spot disease were apparent on all the trees, but the untreated trees were more severely affected than those in the dusted plat. Not only was the defoliation greater on the untreated trees, but the foliage that remained was turning yellow and was of little value to the trees (fig. 76). A comparison was made of the trees in the fourth row of each plat. The amount of defoliation was determined by counting the leaf scars on the trees where leaves were missing. The figures in the third column of table 8 indicate the number of leaves that remained on the trees in addition to those lost by premature defoliation Approximately seventeen per cent of the leaves in the dusted plat were lost prematurely, as compared with sixty-eight per cent for the untreated trees.

LEAF SPOT OF QUINCE[8]

No experiments were conducted in 1915 for the control of the quince leaf spot.

Experiment in 1916

An entire block consisting of eight rows of two-years-old quince trees was used in the experiment in 1916. There were several varieties of quince trees in the block, and the rows, which were about 1100 feet in length, were divided into six experimental plats, a part of each row being included in each plat. Starting at the north end, the trees in plat 1, 100 feet long, were sprayed with lime-sulfur solution one to fifty; plat 2, 100 feet long, was left untreated; plat 3, about 600 feet long, was dusted with the mixture of sulfur and arseniate of lead; plat 4, 100 feet long, was sprayed with lime-sulfur solution; plat 5, 100 feet long; was not treated; and plat 6, about 200 feet long, was dusted (fig. 77).

An attempt was made to give the trees the first treatment previous to the infection period of May 14 to May 17, but weather conditions made it necessary to delay this first application until May 26. On that date the first cluster of new leaves was well developed and the delay in making the first application had permitted considerable infection to occur. These infections were apparent when the second application was made, on June 12. Subsequent treatments were given on June 23, July 6, July 20, and August 9. On July 20 the affected leaves were more numerous on the untreated trees than on those that were dusted or sprayed. This condition was especially noticeable when the trees were examined again on August 9.

Final data on the experiment were recorded on September 19, all records being made from trees in the sixth row. These trees were of the variety Rea's Mammoth, and appeared to be slightly more susceptible to the leaf spot disease than did any of the other varieties. Twenty trees in each of plats 3, 4, and 5 were selected for determining the results of the experiment. In the dusted plat a record was taken of every twentieth tree in the row, and in the other two plats every fifth tree in the row was selected.

The approximate number of leaves originally on each tree was determined by counting the leaves present and the leaf scars where leaves were missing. A tabulation is given in table 9 of the total number of

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[8] The leaf spot disease of quince is caused by the fungus *Fabræa maculata* (Lév.) Atk.

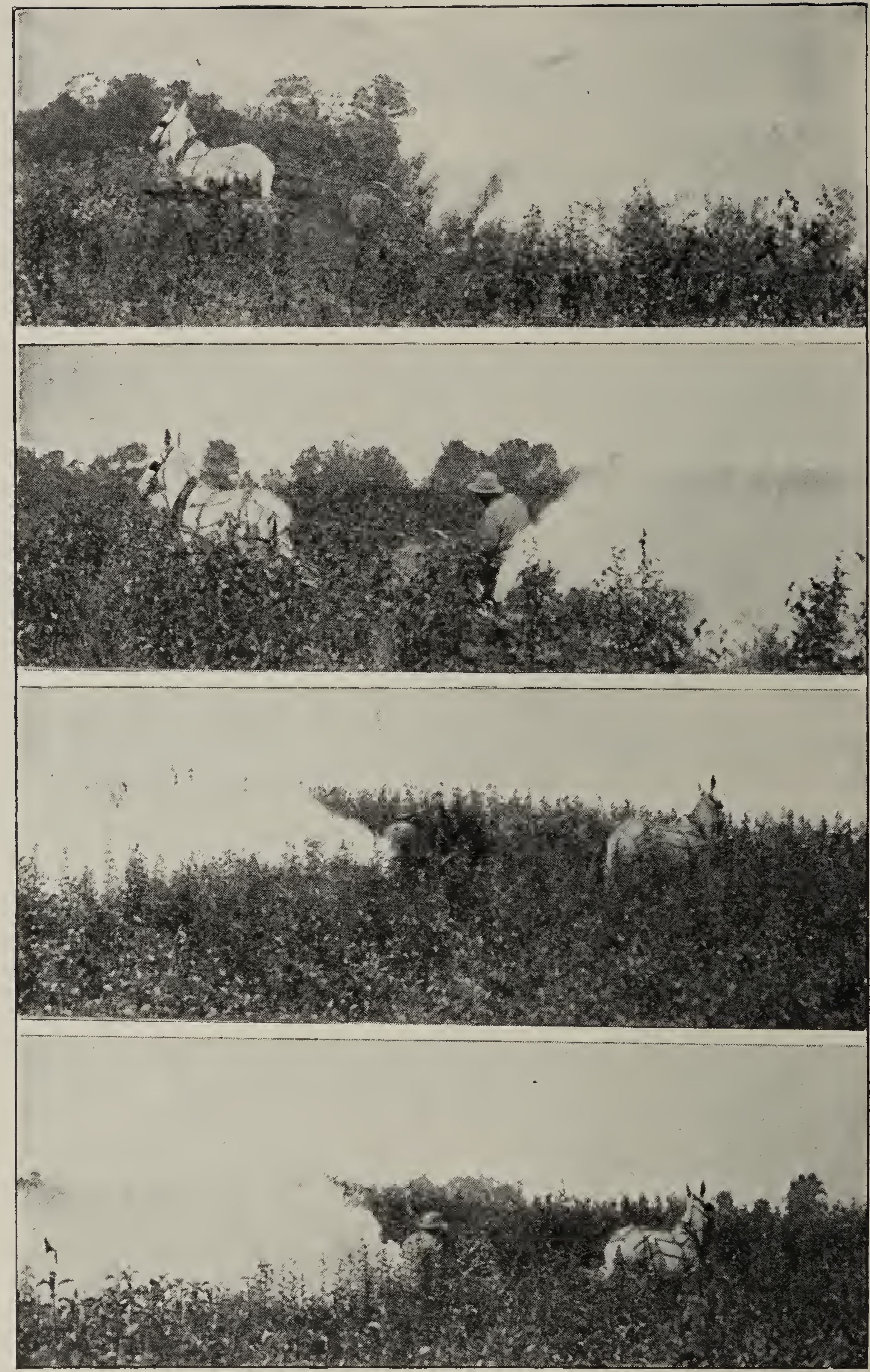

FIG. 77. DUSTING TWO-YEARS-OLD QUINCE TREES

The dust mixture floats like smoke through several rows of trees, completely covering the foliage. Photograph by C. R. Crosby

TABLE 9. DUSTING AND SPRAYING EXPERIMENT WITH QUINCE TREES IN 1916

Treatment	Number of trees from which data were recorded	Total number of leaves originally on trees	Non-infected leaves present		Diseased leaves present		Leaves missing	
			Number	Mean percentage	Number	Mean percentage	Number	Mean percentage
Untreated....................	20	3,579	21	0.66 ± 0.17	2,091	58.65 ± 2.07	1,467	40.68 ± 2.13
Sulfur 90, powdered arsenate of lead 10....................	20	3,451	2,565	74.28 ± 1.44	619	18.05 ± 1.09	267	7.66 ± 0.89
Lime-sulfur solution 1 to 50.....	20	3,215	2,226	69.39 ± 1.82	735	22.52 ± 1.60	254	8.07 ± 0.71

leaves originally on the trees, and the number and mean percentage of leaves not infected, of diseased leaves, and of leaves lost by premature defoliation.

The relatively high percentage of diseased leaves, and also of defoliation, on the trees in the treated plats is attributed principally to the infections that occurred during the period from May 14 to May 17, before the first application was made. Very little of the foliage that developed subsequently was affected. Practically all of the leaves remaining on the untreated trees were diseased, and it was very apparent that the number of infections on each leaf was much smaller on the treated trees. Approximately forty per cent of the foliage was missing from the untreated trees, as compared with seven per cent on the dusted trees.

SCAB DISEASE OF APPLE[9]

For several years the apple scab disease has been very destructive on certain varieties of apples in some of the nurseries of New York State and considerable damage has resulted from premature defoliation of the affected trees. The varieties of apples most commonly attacked by the scab fungus are Transcendent, Martha, and McIntosh, although the disease usually may be found to some extent on all varieties. On McIntosh trees, particularly, the fungus often attacks also the twigs and the branches, causing lesions which, along with premature defoliation, check the growth of the trees.

In 1916 several rows of two-years-old McIntosh trees in a nursery were so severely affected by the scab disease that only a small proportion of them made sufficient growth to be graded as first-class stock. Generally two- and three-years-old trees are more severely affected, but usually enough infections occur in the first-year-apple buds to enable the fungus to become established in the block. The diseased leaves fall to the ground, where they remain as a source of inoculum for the new foliage that develops the next year, and if weather conditions are favorable the scab disease appears in great abundance early in the season. The difference in varietal susceptibility to the scab disease is shown in figure 78. The trees on the left are of the variety Excelsior and have lost practically none of their foliage, while the Martha trees in adjoining rows show a large amount of defoliation.

No experiments were conducted in 1915 for the control of the scab disease on apple nursery stock.

Experiment in 1916

On May 26, 1916, attention was called to several rows of three-years-old Martha apple trees which were severely affected with the scab disease.

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[9] The scab disease of apple is caused by *Venturia inæqualis* (Cke.) Wint.

Primary infection by the apple scab fungus had occurred during the rain period of May 14 to May 17, and it was impossible to find a single leaf that was not diseased. In anticipation that the trees would make more new growth, an experiment was planned to protect the new foliage that would develop subsequently. The rows of trees were divided into three experimental plats. Plat 1 was treated with lime-sulfur solution diluted one to fifty; plat 2 was not treated; plat 3 was dusted with the mixture of sulfur and powdered arsenate of lead.

Applications were made on May 26, June 12, June 23, and July 6. After the application of July 6 the experiment was abandoned, owing to the fact that the trees failed to develop new foliage after the infection in May. No data were obtained as to the effectiveness of the spray liquid and the dust mixture in preventing the scab disease. On the other hand, when the trees were observed on October 2 for the last time it was not difficult to distinguish between the treated and the untreated trees. The untreated trees were almost completely defoliated, while not only more foliage remained on the treated trees but also the leaves were less severely affected. Apparently the fungicides prevented considerable secondary infection on the foliage that was already diseased. Undoubtedly an application of the fungicides before May 14 would have been effective in preventing a large part of the primary infection. The results of the experiment performed emphasize again the importance of making the applications at the opportune time. In this case the trees were so severely damaged early in the season that they failed to recover sufficiently to develop new leaves and continue growing throughout the summer. The defoliated Martha trees illustrated in figure 78 are of the same age as,

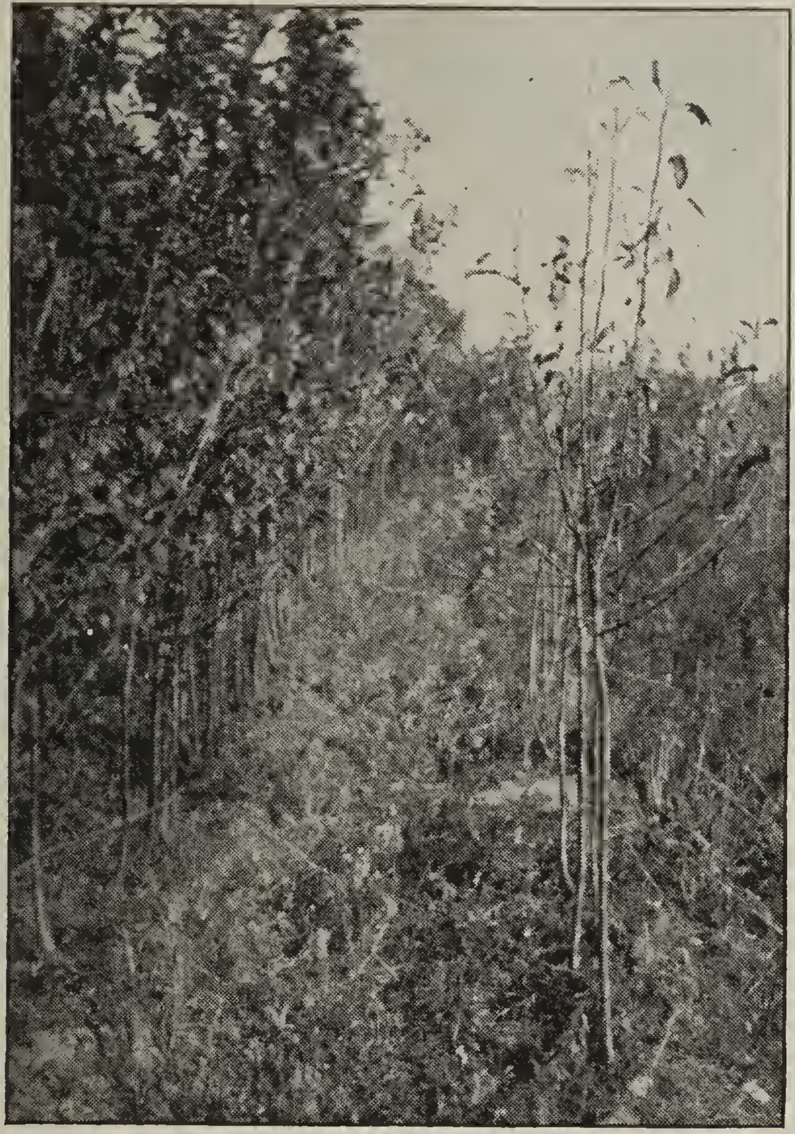

FIG. 78. VARIETAL SUSCEPTIBILITY OF APPLE TREES TO THE SCAB DISEASE

The defoliated trees on the right are of the variety Martha; those on the left are of the variety Excelsior. Although of the same age the defoliated Martha trees made less growth and were smaller than the Excelsior trees, which were not affected by the scab disease. Photographed September 14, 1916 but much smaller than, the Excelsior trees, which were not affected by the scab disease.

MILDEW OF ROSE[10]

Experiment in 1915

In 1915 an experiment was conducted for the control of the powdery mildew fungus on large Crimson Rambler rosebushes. The bushes were planted thickly and formed an arbor several hundred feet in length. A number of these bushes were dusted with the mixture of sulfur and powdered arsenate of lead by means of a hand duster, the first application being made on June 18, just as the mildew began to appear. Subsequent applications were made on July 12, July 21, and August 5. The applications of the dust mixture prevented the attacks of the mildew fungus throughout the growing season, and the bushes retained their beauty and appeared green and healthy until late in the autumn. The untreated bushes were severely affected by the mildew, and by midsummer many of the leaves and shoots were dried out and killed by the fungus.

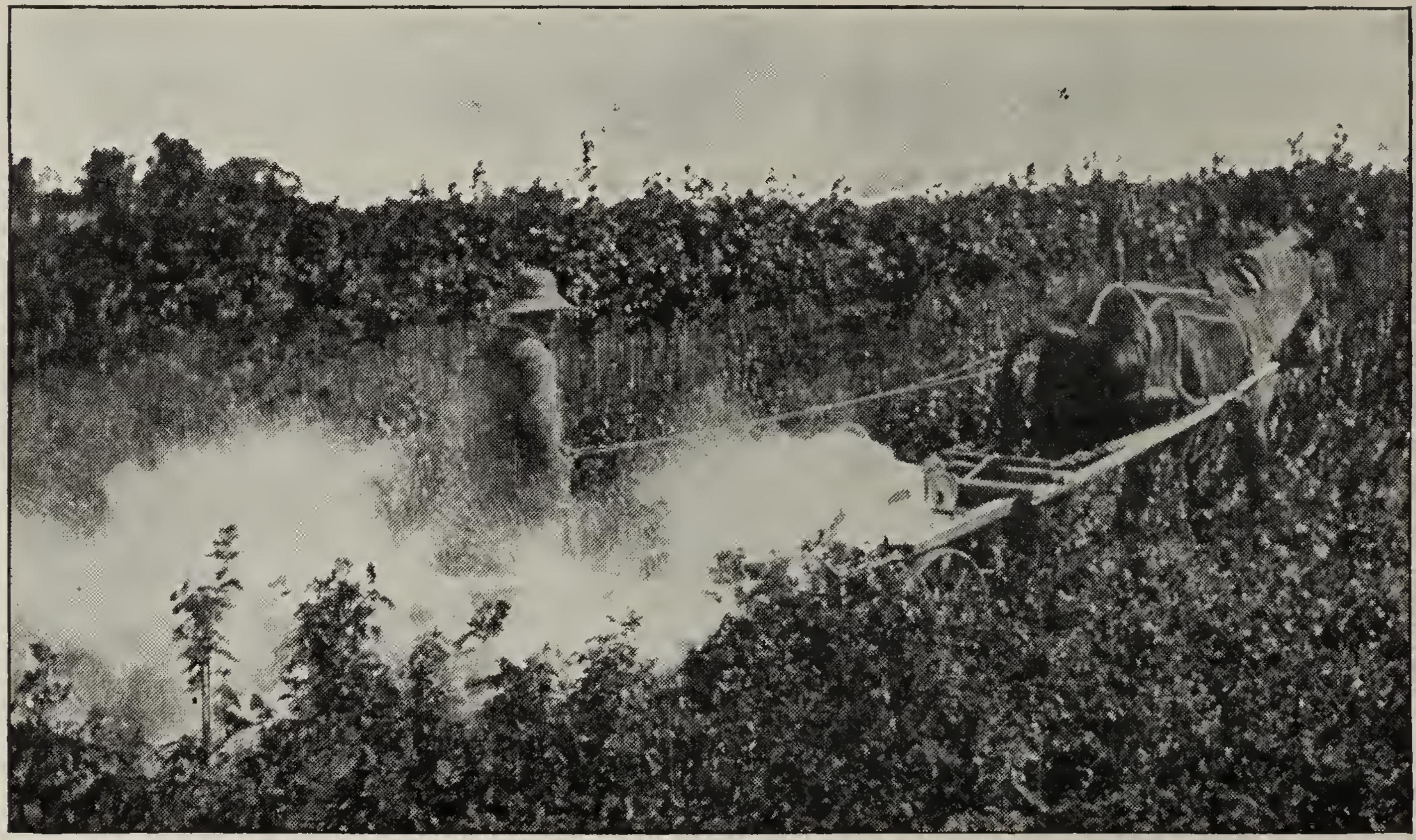

FIG. 79. DUSTING ROSES
This machine was used also for dusting the large horse-chestnut trees shown in the distance

Experiment in 1916

The same rose arbor was dusted again in 1916, on a more extensive scale, the dust mixture being applied by a traction machine (fig. 77). About 100 feet of the arbor was left untreated for a check. The first application was made on July 6 and subsequent treatments were given on July 20 and August 9. Although another application later in the season would have been desirable, the dusted bushes were only slightly affected, while the mildew had caused considerable injury on the untreated bushes when they were observed for the last time on October 2. It is to be noted also that there was much less defoliation caused by the black spot fungus on the treated bushes than on those that were not dusted.

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[10] The mildew of roses is caused by *Sphærotheca pannosa* (Wallr.) Lév. var. *rosæ* Wor.

GENERALIZATIONS

The results of the experiments for the two years indicate that the dusting method is the more satisfactory means of treating nursery plantings for the control of leaf diseases. Where there has been a comparison of dusted plants and sprayed plants, the dust mixture has proved as effective as, and in most cases slightly more effective than, the lime-sulfur solution. This is particularly true for the leaf diseases of horse-chestnut and quince trees.

In certain experiments satisfactory control results were not obtained. These failures, however, can be attributed to causes such as failure to make the applications at the proper time, rather than to a lack of effectiveness on the part of the dust mixture. Furthermore, in each case in which the dust mixture did not control the disease the lime-sulfur solution also failed. Apparently, good control results may be expected if the applications are made so as to protect as much as possible of the foliage throughout the growing season.

Materials to be used

In all the experiments conducted in the nursery, a dust mixture was used consisting of ninety parts of finely ground sulfur and ten parts of powdered arsenate of lead. The arsenate of lead was added, not only for its value as an insecticide against chewing insects, but also, and primarily, for its adhesive properties. When lead arsenate is moistened there is a tendency for it to become somewhat gelatinous and sticky, thus increasing the adhesiveness and spreading quality of the mixture. The dust mixture is considerably more expensive than the lime-sulfur solution. On the other hand, the actual total expense for the dusting method is but slightly greater than for the liquid, since the handling of a large bulk of water is eliminated, the outfit as compared with a power sprayer is less expensive, and the operators are fewer in number. But, above all, the increased cost of the dust mixture is largely offset by the great saving in time, and especially by the ability to cover large areas at critical periods in a minimum of time. Only one man and a horse are necessary to operate the dusting machine, which runs between the rows and thoroughly dusts four rows of stock of any height found in the nursery (figs. 77 and 79). In some plantings, such as currants, the number of rows treated at one time often may be increased to six or seven. There is practically no delay in refilling the hopper, and the horse should walk at a rapid gait in order that there be no waste of the dust mixture.

Cost of the dust and spray methods

In the block of quince trees (page 353), which consisted of eight rows, four rows were thoroughly dusted at one time. Considering the time required for the horse with the machine to walk the distance of the block and return, only fifteen minutes were necessary to dust the entire area of two-thirds of an acre. Thirty-five pounds of dust mixture was used in covering the eight rows. The cost of the dust mixture for one application was $1.90; and with 15 cents added for labor, the entire block could be dusted within fifteen minutes at an estimated cost of $2.05, equivalent to about $3 an acre.

Judging from the time required to spray the quince experimental plats with hand machines, it would have taken one man eight hours to thoroughly spray the entire block of trees. Figuring the cost of the spray solution plus the cartage of water at 35 cents, and estimating the cost of eight hours labor at $1.60, one application of spray solution could be made for $1.95.

The slight increase in cost of the dusting method is of little importance considering the fact that the work can be done so much more quickly and thoroughly as compared with the spraying method. The ability to cover large areas in a minimum length of time is of primary importance when making the applications just previous to periods of weather favorable for infection of the leaf spot diseases.

A suitable spraying outfit would no doubt reduce somewhat the cost of spraying and afford a means of covering certain stock more rapidly than by hand sprayers. On the other hand, there are on the market no power spraying machines that can be used to advantage in treating plantings of nursery stock varying from one to seven or more feet in height. Furthermore, the labor required to operate a power sprayer is a special item. During the rush of other work in the nursery there is often a tendency to delay spraying until it is too late for the application to be effective. This difficulty is largely overcome with the dusting method, since the dusting can be done more quickly and with less labor, making it unnecessary to sacrifice other nursery work.

The ten-per-cent addition of powdered arsenate of lead to the finely ground sulfur greatly increases the cost of the dust mixture, and it is believed that the amount of arsenate of lead could be materially reduced without decreasing the effectiveness of the mixture. On the other hand, the addition of arsenate of lead is often desirable for certain applications when treating stock infested with chewing insects, such as rose and currant worms, and slugs on pears, cherries, and quinces. The arsenate of lead also improves the flowing qualities of the dust mixture, there being a tendency for pure sulfur to lump and clog and not flow freely from the duster. In certain experiments of Reddick and Crosby [11] this difficulty was overcome by the addition of hydrated lime. But there is some evidence that the lime reduces the fungicidal value of the mixture.[12] Besides, the mixture of sulfur and arsenate of lead appears to have higher adhesive quality than any other sulfur mixture. Experimental work should be continued in the nursery to test different sulfur mixtures in order that the cost of the dust mixture may be reduced as much as possible.

SUMMARY

The results of the experiments performed in 1915 and in 1916 indicate that the application of suitable powdered materials, with air used as a carrier, will control certain leaf diseases of nursery stock as well as does the commonly employed fungicide applied as a spray with water as a carrier.

The dust mixture of ninety parts of finely ground sulfur, practically all of which would pass through a screen of 200 meshes to the inch, and ten parts of equally fine powdered arsenate of lead, controlled the leaf diseases of horse-chestnut, currant, plum, cherry, quince, and rose in the nursery. It is reasonable to believe that the same results might be expected for the control of these diseases under other conditions, such as on cherry, quince, and plum trees in the orchard, or on mature currant bushes.

The dusting method is slightly more expensive, but the applications of the dust mixture can be made in a much shorter time and more thoroughly than can spraying with the usual machines now employed by nurserymen.

Experimental work should be continued, not only to test less expensive dust mixtures in order that the cost of the dust method may be reduced as much as possible, but also to test the value of the dusting method for the control of other leaf diseases found in the nursery.

In conclusion, too much emphasis cannot be laid on the necessity of using in the dust mixture only extremely finely ground materials. The fine materials will stick and adhere to the foliage, while the coarser materials merely roll off the leaves and are of little or no value.

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[11] Reddick, Donald, and Crosby, C. R. Further experiments in the dusting and spraying of apples. Cornell Univ. Agr. Exp. Sta. Bul. 354: 53–96. 1915.

[12] Blodgett, F. M. Further studies on the spread and control of hop mildew. New York (Geneva) Agr. Exp. Sta. Bul. 395: 29–80. 1915.

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CORNELL UNIVERSITY
AGRICULTURAL EXPERIMENT STATION

PHYSIOLOGICAL STUDIES OF BACILLUS RADICICOLA OF SOYBEAN (SOJA MAX PIPER) AND OF FACTORS INFLUENCING NODULE PRODUCTION

J. K. WILSON

ITHACA, NEW YORK
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PHYSIOLOGICAL STUDIES OF BACILLUS RADICICOLA OF SOYBEAN (SOJA MAX PIPER) AND OF FACTORS INFLUENCING NODULE PRODUCTION

J. K. Wilson

From a consideration of the literature of the subject it becomes apparent that there is a lack of fundamental information with respect to the morphological and physiological characteristics of the bacteria causing nodule production in leguminous plants, and that no thoro investigation has been made of the factors controlling nodule production. Moore (1905)[1] has stated that these factors vary with each member of the legume family and depend on the requirements of the host plant. In order to increase the knowledge of this subject, the writer has concluded investigations on the organism causing nodule production on soybeans and the factors influencing nodule production on this host. The soybean organism was selected for investigation because of its distinctive cultural characteristics and because of the increasing importance in New York State of the soybean as a crop.

The investigation includes study of the following points:

1. Morphological and physiological characters of the organism causing nodule production on soybeans.

2. Factors that may influence the formation of nodules on soybeans grown in soil or water cultures, using not only the salts that are essential for the development of the plants but also non-nutrient salts and various other substances. An effort was made to determine also the relation of the soil moisture content to the formation of nodules.

3. Vitality of *Bacillus radicicola* of soybean under different cultural conditions. An attempt was made here to determine whether or not inhibition of nodule production is due to death of the organism or to other causes.

4. Time required for infection. This includes, by indirect evidence, the time required for the organism to gain entrance into the root.

5. Is nodule production associated with the nitrogen requirement of the plant?

REVIEW OF LITERATURE

Relatively little work has been done to determine the influence of various substances on nodule formation, despite the fact that over sixty years ago Rautenberg and Kühn (1864), in investigations with *Vicia Faba*, incidentally observed that no nodules were formed on the plant roots when they were grown in various solutions containing nitrates.

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[1] Dates in parenthesis refer to bibliography, page 412.

No more observations are noted until De Vries (1877) presented the results of his work with red clover. He found also that when plants were grown in full nutrient solutions containing nitrates at certain concentrations, the formation of nodules was inhibited.

Vines (1888–89), experimenting with *Vicia Faba*, employed soil cultures with boxes as the containers, and grew the plants both in the greenhouse and in the open. The beans were soaked in a nitrate solution before planting, and the solution was added to the soil after the beans were planted. Vines examined the roots after pulling up the plants. He concluded that the production of nodules was much less when a nitrate was present in the soil than when it was absent. His work indicates also that as the supply of nitrates decreases the number of nodules increases, and he advanced the idea that nodule production is associated with certain conditions of nutrition.

The same year Frank (1889) grew lupines and peas, on the one hand in a humous soil and on the other hand in a humus-free soil, and observed that nodules were freely formed in the latter case but none were produced in the former.

The effect of moisture on nodule production was noted by Gain (1893). He grew *Pisum sativum*, *Lupinus albus*, and *Faba vulgaris* in an arid section, watering some of the plants and leaving the remainder unwatered. Not only did the watered plants have a larger number of nodules, but the nodules were differently located. The beans that were watered produced several times as many nodules as did those that were left unwatered.

Hellriegel (1895) also made observations on the factors influencing nodule production. He says: "The best development and largest number of the tubercles are attained in soils quite free of nitrogen, and if the soil contains very much nitrogen the formation of tubercles may be altogether suppressed even when the fungus necessary to produce them is present."

The effect of calcium oxid on nodule formation has been observed by Salfeld-Lingen (1900). In 1893 he applied 2000 kilograms of quicklime per hectare to light sandy soil and in 1894 observed its effect on nodule production. Where the lime was applied the pea plants were dark green and the roots rich in nodules, while on the check field the plants were yellow and no nodules were found.

Marchal (1901) determined the concentrations of various substances that prevented nodule formation in Sachs' solution, which presumably had the following composition:

Potassium nitrate	1.0 gram
Sodium chloride	0.5 gram
Calcium phosphate	0.5 gram
Calcium sulfate	0.5 gram
Magnesium sulfate	0.5 gram
Water	1000 cubic centimeters

His conclusions may be briefly summarized as follows: The alkaline nitrates in concentrations of 1 to 10,000 and ammonium salts in concentrations of 1 to 2000 prevent nodule formation. The salts of potassium and of sodium behave similarly in concentrations of 1 to 200 and 1 to 300, respectively. The salts of calcium and of magnesium favor the production of nodules on the roots of the plants. Phosphoric acid has a stimulating effect. Marchal believes that the osmotic relationships are concerned with the inhibition of nodule formation.

Malpeaux (1901) also has observed the action of nitrates on nodule production of lupines. The addition of nitrate of soda diminished nodule formation and in a certain concentration prevented nodule development.

Laurent (1901) has contributed more extensively to this subject. He employed a variety of peas, and used small soil plats which were fertilized with a number of substances in excess of what the plants would use. He found: (1) that plants from the ammonium sulfate plat had only a few nodules, these being distributed over the lateral roots; (2) that plants from the plat receiving potassium salts were abundantly provided with nodules, which were massed together on the main root; (3) that with superphosphate of lime present, plants showed abundant formation of nodules, which were massed together on the principal roots; (4) that lime alone stimulated nodule production in great masses; (5) that sodium chloride stimulated the formation of numerous small nodules.

Wohltmann (1902) grew Canada field peas in a variety of soils and with a number of different treatments. He concluded that ammonium nitrate, if applied in liberal quantities, may reduce the number of nodules. Plants grown in one soil, no matter what treatment was applied, produced no nodules. Wohltmann points out that these results are significant with respect to the choice of fertilizers in relation to their effect on the bacteria in the soil.

Moore (1905) states that the alkaline nitrates in the proportion of 1 to 10,000 are sufficient to prevent the formation of nodules, and shows by photographs that soybeans grown in a poor sandy soil and in a poor clay soil have a greater supply of nodules than plants grown in a rich nitrogenous soil. He states also that fully as striking differences might be shown in a soil in which the moisture or the acidity or the air supply varies, and that the application of calcium or magnesium will act differently on nodule production depending on whether the plant grows under acid or under alkaline conditions.

Donnan (1912) observed that lucern plats which received lime as a fertilizer in connection with inoculation experiments showed a very great increase in the number of plants with nodules and also an increase in the number of nodules per plant; where no bacterial culture was used for lucern, however, the presence of lime caused practically no difference in nodule formation. Also, "complete manure did not, on the total throughout, increase the number of nodules, although an increased growth of both stem and root was caused by its application."

Eichinger (1913), in testing the value of fertilizers in connection with inoculation experiments for soybeans, cowpeas, and other crops, observed that superphosphate increased the production of nodules, whereas sodium nitrate inhibited nodule formation.

Prucha (1915), in experiments with Canada field pea, found that certain substances when added to water culture or soil culture materially influenced nodule formation. The nitrates of calcium and potassium, as well as the chlorides of ammonium, calcium, and iron, when added to the soil in certain quantities inhibited nodule formation. This was true also of saccharose and of Witte's peptone. On the other hand, potassium dihydrogen phosphate, magnesium sulfate, potassium hydroxide, calcium phosphate, calcium sulfate, tannic acid, and starch, exerted a beneficial influence on nodule development. In water culture the presence of nitrogen as calcium nitrate or as potassium nitrate depressed nodule formation. Prucha determined also the influence on nodule formation of aëration, of some nutrient solutions, and of potassium nitrate, in light as compared with darkness. Aëration had no influence as measured in this work. A smaller number of nodules developed in light than in darkness.

In concluding a review of the literature it may be said that there are many factors which have more or less bearing on nodule formation and it is doubtful whether any one of the investigators has properly controlled all of them. This is especially so with all field tests, for here it is impossible to control the moisture relations and the concentration of the soil solution, both of which are known to bear intimate relations to nodule formation. Those who have worked with water culture have more nearly approached an ideal condition, at least a condition in which they have controlled many of these known influences. There are undoubtedly many factors, such as temperature, age of the root, age of the entire plant, its condition of thrift, and the like, which bear some relation to nodule formation and which have been given little or no consideration in work of this kind. Whether these unknown influences are potent enough to materially alter the results already obtained can be told only as more light is thrown on this subject by experimental work.

METHODS OF THE PRESENT INVESTIGATION

A somewhat definite outline of the methods employed in the experiments reported in this bulletin is necessary and is here given. The experiments made, unless otherwise indicated, were conducted in accordance with these methods.

The medium

The medium employed for the isolation and cultivation of *Bacillus radicicola* of soybean is a modification of Ashby's medium and was prepared according to the following formula:

Dibasic potassium phosphate	0.2 gram
Magnesium sulfate	0.2 gram
Sodium chloride	0.2 gram
Calcium carbonate	0.2 gram
Calcium sulfate	0.2 gram
Agar	15.0 grams
Saccharose	20.0 grams
Tap water to make	1000 cubic centimeters

Test tubes were prepared containing from 6 to 10 cubic centimeters of this solution, and in each tube a crushed soybean was placed.

Sterilization of media and utensils

Strict precautions were observed in securing sterile material wherever it was necessary. All the media used for pure cultures, when in small volume, were sterilized in the autoclave for fifteen minutes at 15 pounds pressure. Media in larger volumes were left in the autoclave for a longer period of time. In the case of soil cultures the containers and the soil were sterilized for two hours at a pressure of 15 pounds.

Sterilization of seed

For certain experiments it was desirable to have seed free not only of *B. radicicola* but also of all other organisms. To this end, seeds were treated for three hours in a solution of calcium hypochlorite (Wilson, 1915) containing approximately 2 per cent of chlorine. After this treatment they were transferred to the culture containers.

The organism

The original culture for investigation was made from a stock culture which had been kept in the laboratory for two years or more, the exact date of isolation not being known. Transfers had been repeatedly made during this period, employing the medium previously described. This stock culture had also been repeatedly tested for its ability to produce nodules, with positive results. It was the culture from which hundreds of pure cultures have been prepared for distribution to farmers of the State.

Culture methods for plants

Both soil and water cultures were employed. The soil cultures were prepared by placing the equivalent of 208 grams of dry soil in glass tumblers having a capacity of approximately 250 cubic centimeters. The moisture was controlled after the seeds were planted. For the water cultures tumblers were used in some experiments, and in others glass cylinders of about 4700 cubic centimeters capacity were substituted. The solutions for these containers were prepared from stock solutions, placed directly in the container, and covered immediately with paraffin paper, which was held firmly to the container by a string or a rubber band. Plants grown in these culture solutions were not under strictly sterile conditions, yet in no case did the control cultures show nodule production.

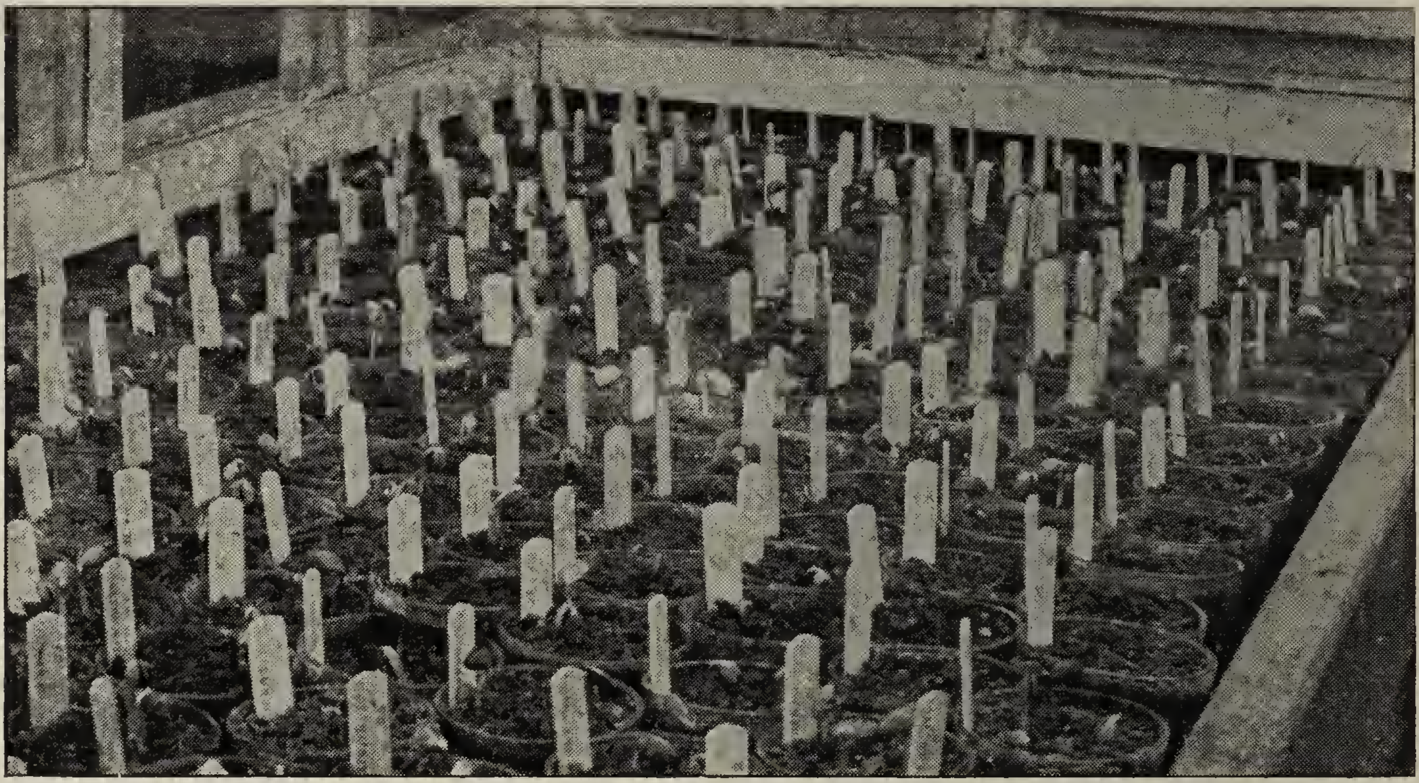

FIG. 80. METHOD OF ARRANGING SOIL CULTURES

The soil cultures for testing the vitality of *B. radicicola* under various cultural conditions were prepared in glass tumblers (page 400). Each tumbler was filled to within two centimeters of the top with air-dry, sandy soil, covered with heavy wrapping paper, and sterilized as previously described. These tumblers were kept covered until planting time, when the covers were removed only long enough for planting the seeds and watering. The cultures were then transferred to the greenhouse and placed in an especially constructed culture room (fig. 80). Here they remained covered until the plants were in need of light for growth. This required five days out of the fourteen which were allowed for nodule development. The remaining nine days were not sufficient to permit disturbing conditions.

Inoculation of plants

The same methods were used to inoculate both soil and water cultures. The cultures were inoculated twenty-four hours after planting, the method being as follows: A small quantity of water was added to a fresh growth of the organism on an agar slope. The growth was then loosened by means of a platinum loop, and added to 100 cubic centimeters of sterile water. In order to secure inoculation a definite amount of this infusion, usually 5 cubic centimeters, was added to each culture. Platings of this infusion showed as many as 10,000,000 germs per cubic centimeter.

Examination of roots for nodules

Repeated trials showed that nodules macroscopically visible will develop under favorable conditions in fourteen days. However, in order to show the influence of certain factors on nodule formation and to eliminate all doubt as to the results obtained, and also to make the results more decisive, the roots were not examined in many of the experiments until after a considerably longer time had elapsed. In all cases the exact time is indicated. In determining the presence or the absence of nodules and the number produced in soil culture, the roots were first freed of soil by gently washing them and the counts were then made. For purposes of comparison the nodules are arbitrarily classed under groups, the classification being based on size and distribution; those 1 millimeter or more in diameter are designated as large, and those less than 1 millimeter in diameter are designated as small.

The culture room

In order to prevent contamination of the plant cultures growing in tumblers with *B. radicicola*, and to reduce evaporation from the free surfaces of the exposed containers, an especially constructed culture room was provided in the greenhouse. To secure ventilation certain panes of glass were replaced by frames fitted with layers of cotton held in place by cheesecloth. In winter these frames could be removed when necessary and replaced by frames containing glass. Cracks in the walls between the glass parts were filled with plaster of paris. The floor and the benches were covered with cinders so as to reduce danger of contamination thru dust. Before using the room the walls and wooden parts were always thoroly washed.

Watering the plants

The water cultures had enough of the solution to supply their needs during the experimental period. With the soil cultures it was different. In order to maintain an optimum and somewhat definite moisture condition for growth it was necessary to water the plants every day. In all experiments, unless otherwise stated, distilled water was used. This was necessary in order to avoid the addition of substances that might have an influence on nodule formation.

Growing plants under sterile conditions

In determining the causal organism of nodule production, nodules must be produced in the presence of only the one organism in question. To accomplish this, it is necessary to grow the plant and the organism to the exclusion of all other forms of life. For this purpose a long-necked, flat-bottomed, four-liter flask was used in these experiments. In this flask was placed 1800 grams of sandy soil with a moisture content of about 16 per cent. The flask was plugged with cotton, thru which passed a glass tube with a bore large enough to allow the passage of a soybean. This tube also was plugged with cotton. At the time of seed planting the upper end of the glass tube was heated, the cotton was removed, and the seed was taken from the disinfecting solution and put into the flask thru the tube. The tube served also in placing and burying the seed, as well as providing an inlet for introducing the suspension of bacteria for inoculation.

Obtaining plantlets for water cultures

Soybeans (of the variety Hollybrook) were placed in a vessel, soaked in running water for three or four hours, and germinated between filter paper. Within a week germination was usually sufficiently advanced so that when brought into the light the cotyledons would turn green. At this stage they were ready for use, and the hypocotyl could be inserted into the culture solution thru a hole in the covering of the vessel.

Soil type used

In order to have as uniform conditions as possible for experiments of this kind, a well-defined New York State soil type was selected. This type was chosen mainly because of its accessibility and its agricultural importance. Owing to its water-holding capacity, the Volusia silt loam soil is adapted mostly to annual plants, especially the annual legumes, the biennial plants failing because of frequent heaving of the soil in winter or because of the deficiency in the soil of some particular element, probably calcium.

The soil for the experimental work was procured from a farm in the vicinity of Ithaca. This soil had not been cultivated for at least twenty years, if at all, for it was taken from a strip dividing two fields. Since this soil had not been cultivated, it is probable that no kind of fertilizing material had ever been added to it.

On October 16, 1913, the top six or seven inches of soil from this field was brought to the college greenhouse and thoroly mixed after screening. The screenings were discarded. This mixed soil was placed in boxes, each box being filled and kept thoroly tight so that only a slight amount of moisture was lost. As soil was needed it was taken from the box, a moisture determination was made, and then enough soil was weighed into tumblers to equal 208 grams of dry soil. The chemical to be added to the soil, if soluble, was dissolved in just enough water so that when this was added to the soil it would give a moisture content of approximately 35 per cent of the dry weight of the soil. This percentage of moisture was used in all the soil tests. If the substance to be added was not soluble it was mixed with the soil, and the amount of water necessary to make a moisture content of 35 per cent was then added. This water content was maintained constant by daily weighings and addition of the necessary quantity of water.

Necessity of artificial inoculation

It is a common observation that leguminous plants which are grown on a soil for the first time may be void of nodules. Therefore, in order

TABLE 1. RESULTS OF EXPERIMENT TO DETERMINE THE NECESSITY OF ARTIFICIAL INOCULATION

Species tested	Nodules
Vigna unguiculata (cowpea)	None
Soja max (soybean)	None
Trifolium alexandrinum	None
Medicago lupulina	None
Medicago sativa	None
Medicago officinalis	None
Medicago falcata	None
Medicago media	None
Melilotus alba	None
Melilotus indica	None
Trifolium pratense	Present
Vicia villosa	None
Vicia sativa	None
Vicia dasycarpa	None
Vicia angustifolia	None

to determine whether it was necessary to inoculate the soil cultures with *B. radicicola*, tumblers were prepared with the Volusia silt loam soil in them and planted with a number of different legume seeds, including soybean. The tumblers were watered daily but no effort was made to maintain a definite amount of water in the soil. The results are presented in table 1.

Of the fifteen leguminous plants grown in this soil, nodules were produced only in *Trifolium pratense*. It is therefore necessary, for nodule production, to inoculate each soybean culture with *B. radicicola* of soybean.

Normal production of nodules

How widely the number of nodules per plant will vary under uniform conditions has not been determined. The data that have been obtained by other investigators along this line are so varied that no conclusions can be drawn. This is probably due to a lack of controlling the many factors influencing nodule production.

In order to obtain data that would be of value in drawing conclusions from the results that follow, a test was made to determine what the normal production of nodules may be in a given soil. A series of tumblers were prepared with soil and planted with soybeans, which were selected for uniformity of shape and size. The various portions of the soil were equally inoculated with the soybean culture and were kept at a definite moisture content by daily weighings. The data from one hundred plants are given in table 2:

TABLE 2. NORMAL PRODUCTION OF NODULES IN SOIL CULTURE
(Duration of experiment, 14 days)

Number of plants examined	Number of nodules	Number of nodules per plant	Number of nodules per plant, average of 50 plants	Number of nodules per plant, average of 100 plants
25	89	3.56	3.70 3.50 3.54 3.64 3.68 3.48	3.59
25	86	3.44		
25	88	3.52		
25	96	3.84		
Average			3.62	
Variation			±0.12	

These data show that the normal production of nodules per plant under the conditions of this experiment is between three and four. This is true no matter whether twenty-five, fifty, or one hundred plants are considered. Figured to a basis of one hundred plants, the normal variation is ± 12. That this number is quite reliable is shown by the results from one hundred and twenty-five plants which were grown as check plants in subsequently reported experiments. These one hundred and twenty-five plants produced 350 nodules per 100 plants and the theoretical number would be 359. Therefore, in the experimental data which follow, the number of nodules per 100 plants which fluctuates more than ± 12 from that shown by the check plants may be considered as due to the condition under which the plants were grown.

IDENTIFICATION OF BACILLUS RADICICOLA OF SOYBEAN

No detailed description of the soybean organism has as yet appeared, tho occasional incidental references are found concerning it. This is undoubtedly due in part to the difficulties encountered in cultivating the organism, in determining its motility, and in staining the flagella.

The source of the culture used in this work has been described and its ability to produce nodules is known. In order, however, to prove definitely that the culture employed was of the soybean organism and not a mixture, the following procedure was adopted for the reisolation of the organism preparatory to a study of the physiological and morphological characters:

1. Soybean plants were grown under sterile conditions and the roots inoculated with the culture.
2. When nodules were developed a new isolation was made from the nodule.
3. The original culture, and the cultures isolated from the nodule produced under sterile conditions, were then studied in the laboratory with respect to their morphological and physiological characters. Their group number was determined according to the descriptive chart of the Society of American Bacteriologists (1907).
4. All the cultures were again tested under sterile conditions for their ability to effect inoculation.

Details of identification methods

For growing plants under sterile conditions the methods previously described were followed. The plants were prepared on December 27, 1913, and were inoculated on the following day with the organism in question. The flasks were then placed in the greenhouse, where they remained until February 28, 1914. At that time they were brought to the laboratory and the roots were examined for nodules. At the same time the soil from the flasks was examined for bacteria by planting it in both peptone beef-extract agar and in the modified Ashby's medium.

There were abundant nodules on the roots of the plants that were grown only in the presence of the organism in question. In seven days the plantings in the above-mentioned media were examined. Those made in peptone beef-extract agar showed no growth at all, while those made in the modified Ashby's medium showed a pure culture of some organism which resembled in every way, as judged from plantings, the organism that was introduced into the soil. The check plant showed no nodule development, and plantings of the soil showed no bacterial growth, on either medium used.

Two of the nodules produced were used for reisolation of the cultures. The pieces of root with nodules were first washed in mercuric chloride solution 1–1000 for two minutes, and then rinsed several times in sterilized water. Plantings of the last water used showed no bacterial growth. Plantings of the interior of these nodules developed a pure culture of some organism resembling in every way the culture introduced into the soil. From one of the plantings a colony was selected which was in all probability produced from one germ. A transfer was made from this colony to an agar slope. The same method was followed in obtaining another culture from a second nodule. These cultures were replanted along with the original culture, and their purity was determined.

A delay of several months occurred before the cultures were compared and their morphological and physiological characters determined. In June their detailed features were determined and a brief characterization was made. The methods for staining the flagella were as follows:

The organism was stained according to Pitfield's method as modified by Muir and Ritchie (1907). The mordant used was made according to the following formula:

	Cubic centimeters
Tannic acid, 10 per cent water solution filtered.......	10
Corrosive sublimate, saturated watery solution.......	5
Alum, saturated watery solution..................	5
Carbol fuchsin..................................	5

These substances were mixed thoroly and filtered before using. The stain consisted of the following:

	Cubic centimeters
Alum, saturated watery solution....................	10
Gentian violet, saturated alcoholic solution..........	2

Films were prepared from cultures on agar which were grown at room temperature for from one day to seven days. A very small portion of the growth was taken on the loop of a platinum needle and carefully transferred to water on a cover glass. This was allowed to dry in the open room, was fixed by passing thru a flame, and was covered with the mordant. The cover glass was covered with as much of the mordant as it would hold, and was heated gently over the flame. It was allowed to steam for about two minutes and was then washed well in running water. When it was thoroly dry the stain was applied, and the cover glass was heated as before for about a minute and then thoroly washed in water.

Examination of preparations made in this way showed that the flagella were peritrichous, the highest number found being four.

A comparison of these three cultures show them to be identical in every particular. They do not form spores, they are facultative anaërobes, and they do not liquefy gelatin either at room temperature (from 20° to 26° C.) or in the ice box (from 10° to 18° C.). No gas nor acid is produced from dextrose, lactose, or saccharose, and nitrates are not reduced. The cultures are colorless on agar slopes altho they are somewhat glistening in character. After two weeks they are slightly brownish, both on agar slopes and on potato cultures. The organism stains readily with most stains, and gives slightly different measurements under different cultural conditions. These measurements may range from 0.6 μ to 1.2 μ broad by from 0.8 μ to 3 μ long. Occasionally X and Y forms are observed, this also depending on the culture medium.

The last step in this determination of the causal organism was to retest all cultures as to their ability to produce nodules. On July 3, 1914, flasks were prepared and sterilized soybeans were planted in them. Three days later transfers from the original cultures, which gave identical characters, were injected into the soil within the flasks, which were then placed in the greenhouse. On July 15 the roots of these plants were examined for nodules.

The original culture and the two cultures which had been isolated from nodules grown under sterile conditions effected inoculation. The roots of the check plants were entirely void of any structures resembling nodules.

Conclusions

It would seem from these data that the organism in question was the one responsible for nodule formation, and that according to its detailed features it is a Bacillus, the flagella being attached to any part of the body. The highest number found in any preparation was four. Its group number, therefore, according to the classification of Migula (1900) and as determined by the descriptive chart of the Society of American Bacteriologists (1907), is B.222.3332033.

Discussion

The results of these findings are in accord with the findings of those who hold that the flagella of the organism are peritrichous and not polar. Its group number is slightly different from that given to *B. radicicola* of Canada field pea by Prucha (1915). He finds that this organism produces acid without gas from dextrose and saccharose. Under the same conditions the culture from soybean grew so little, if at all, that no change was recorded by the method used.

INFLUENCE OF CERTAIN CHEMICAL SUBSTANCES AND OF SOIL MOISTURE ON NODULE FORMATION

As pointed out in the review of literature (page 369), various phases of the subject relating to the factors influencing the formation of nodules have been touched on from time to time. As yet no comprehensive work has appeared. In the investigations herewith reported, the writer has endeavored to determine the influence on nodule formation of a large number of substances both nutrient and non-nutrient, as well as of carbohydrates and other substances, in soil cultures and in water cultures.

Soil cultures. Volusia silt loam

Nitrates

On February 21, 1914, tumblers were filled as has been described, and a number of different nitrates applied to the soil. For each nitrate there were ten tumblers, each containing 208 grams of soil. The rate of application of the different nitrates to this soil was not the same in all cases, because of the variation in toxic effect of the different salts on the plant. The application of the salt is, however, not an arbitrary one, for in a previous experiment of the same nature the optimum concentration for each nitrate was determined for plant growth. The amount of salt added, however, is in all cases in excess of what would be used in field practice; yet the results

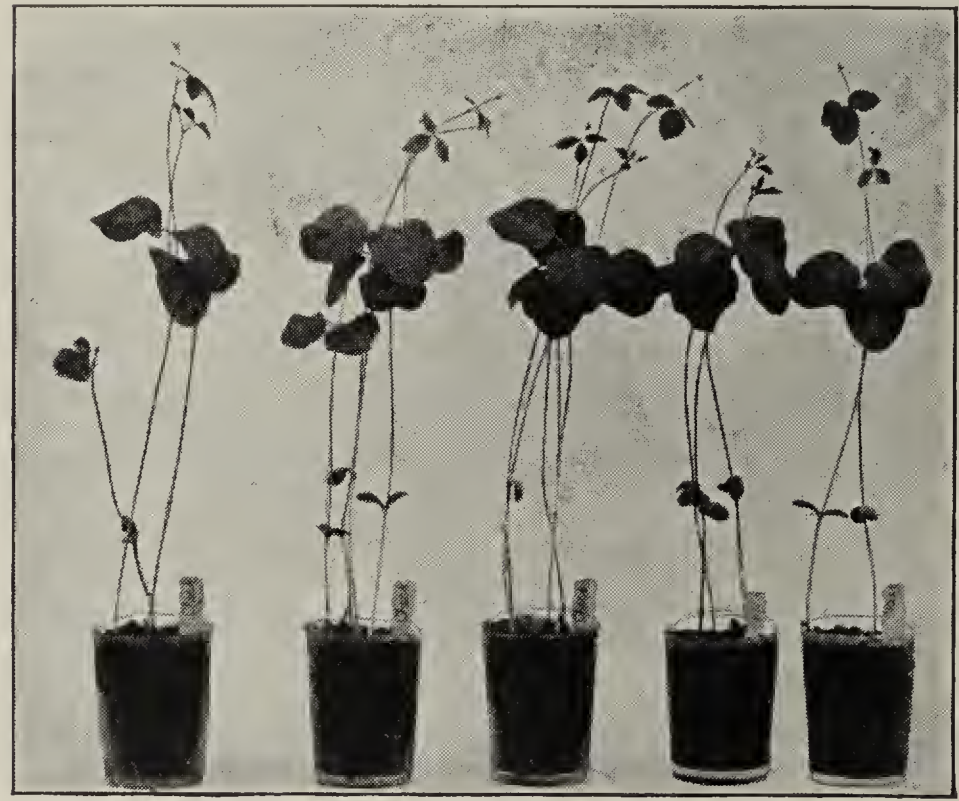

FIG. 81. CHECK PLANTS

are suggestive of what might be expected from the use of nitrates. The data are given in tables 3 and 4.

It is seen from table 3 that as a rule the application of nitrates greatly reduces the number of nodules formed. Of the eighteen nitrates used, only two permitted a total number of nodules greater than 165 per 100 plants. Not only are the numbers and the sizes reduced, but also their location is different. With the check plants a greater proportion of the nodules are on the main roots than is the case with those plants that have been grown under the influence of the nitrates.

In a preliminary experiment in which the plants were examined fifty days after planting, certain nitrates completely checked the appearance of nodules. That this checking of nodule formation is not due to the injurious effect of the nitrate on plant growth is seen from table 4.

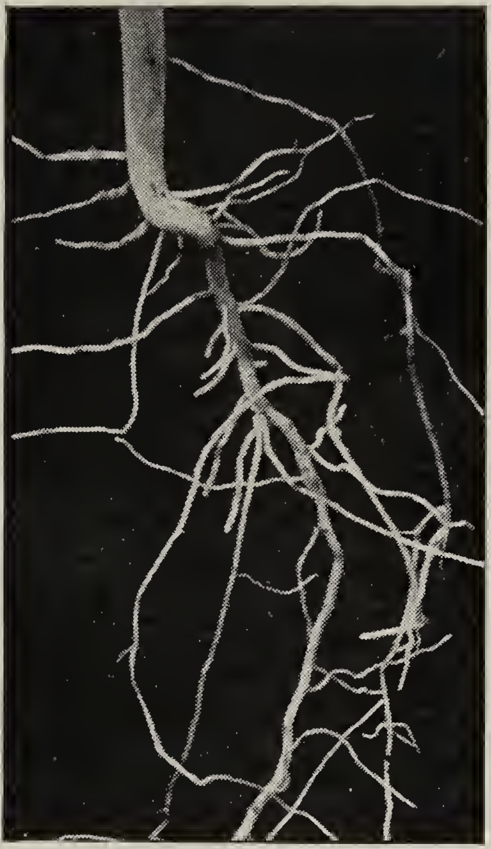

Fig. 82. Root of check plant, natural size, showing small nodules

In this experiment the nitrates were applied

TABLE 3. Influence of Nitrates on Nodule Formation

(In 208 grams of dry soil. Duration of experiment, 30 days)

Substance used	Quantity applied (grams)	Number of plants	Number of nodules on main roots		Number of nodules on other roots		Total number of nodules	Number per 100 plants
			Large	Small	Large	Small		
Calcium nitrate	0.1	63	0	5	0	80	85	135
Potassium nitrate	0.1	44	0	6	0	63	69	157
Ammonium nitrate	0.1	49	0	0	0	4	4	8
Magnesium nitrate	0.1	64	0	3	0	45	48	75
Sodium nitrate	0.1	62	0	8	0	48	56	90
Aluminium nitrate	0.1	60	0	26	0	188	214	357
Barium nitrate	0.1	56	0	13	0	36	49	88
Ferric nitrate	0.1	57	0	8	0	38	46	81
Lead nitrate	0.1	53	0	4	0	8	12	23
Cadmium nitrate	0.02	57	0	0	0	12	12	21
Cerium nitrate	0.1	58	0	13	0	46	59	102
Strontium nitrate	0.1	59	0	0	0	27	27	46
Lithium nitrate	0.1	71	0	6	0	11	17	24
Zinc nitrate	0.05	59	0	10	0	69	79	134
Uranium nitrate	0.1	65	2	20	0	47	69	106
Nickel nitrate	0.02	62	0	30	0	72	102	165
Mercuric nitrate	0.1	62	0	28	0	44	72	116
Nitric acid	0.05	60	8	184	0	15	207	345
Checks	.....	125	22	195	1	220	438	350

in a series of concentrations ranging from what would seem to be a heavy application to a very light one. The test was run in duplicate. With these applications it was possible to tell what concentrations are effective in checking nodule formation, and what ones produce injury to the plants. The former was determined by an absence of nodules, and the latter by an optical comparison of the plants with checks grown under the same condition. The injurious action was usually manifest by difference in root growth, tho sometimes by browning of leaves.

TABLE 4. SHOWING AMOUNT OF NITRATE WHICH INHIBITS NODULE FORMATION, AND AMOUNT WHICH CAUSES INJURY TO PLANTS

(In 208 grams of dry soil. Duration of experiment, 50 days)

Substance used	Amount necessary to inhibit nodule formation (grams)	Amount necessary to cause injury to plant* (grams)
Lithium nitrate	0.2	1.0
Cadmium nitrate	0.1	0.1
Sodium nitrate	0.1	0.5
Calcium nitrate	0.2	1.0
Uranium nitrate	0.1	1.0
Strontium nitrate	0.2	0.5
Zinc nitrate	0.1	0.5
Ferrous nitrate	0.1	0.5
Nickel nitrate	0.05	0.1
Ammonium nitrate	0.1	0.5
Mercuric nitrate	0.1	1.0
Cæsium nitrate	0.2	0.5
Silver nitrate	0.05	0.05
Potassium nitrate	0.05	0.5
Magnesium nitrate	0.5	0.5
Lead nitrate	0.2	0.5
Barium nitrate	0.2	0.5

* The injury to plants was determined by comparing them with check plants grown under similar conditions.

This summary brings out very forcibly that considerably less quantities of nitrates than are necessary to produce injury to the plants may completely inhibit the formation of nodules. This was true in fourteen out of seventeen cases. In the cases of the nitrates of cadmium, silver, and magnesium, the nodule formation stopped with those applied concentrations that injured the plants.

Chlorides

The influence of chlorides on the formation of nodules was tested simultaneously with that of the nitrates, and the same check plants were used in this and the following experiments. Here, as with the nitrates, the application of the chloride is somewhat higher than would usually be applied, but such quantities are often found in the soil. The results are given in table 5:

TABLE 5. Influence of Chlorides on Nodule Formation

(In 208 grams of dry soil. Duration of experiment, 30 days)

Substance used	Quantity applied (grams)	Number of plants	Number of nodules on main roots		Number of nodules on other roots		Total number of nodules	Number per 100 plants
			Large	Small	Large	Small		
Potassium chloride	0.05	58	19	40	3	314	376	648
Sodium chloride	0.05	40	3	40	10	181	234	585
Magnesium chloride	0.05	38	0	9	20	337	366	963
Calcium chloride	0.05	50	3	19	6	492	520	1,040
Cæsium chloride	0.05	55	9	70	11	405	495	900
Bismuth chloride	0.05	50	0	12	7	332	351	702
Rubidium chloride	0.05	52	4	42	0	255	301	579
Lithium chloride*	0.05	50	1	25	1	74	101	202
Cupric chloride	0.05	41	14	28	5	150	197	480
Aluminium chloride	0.05	53	2	9	29	298	338	638
Lead chloride	0.05	45	1	27	8	207	243	540
Ammonium chloride	0.05	39	0	19	0	29	48	123
Manganese chloride	0.05	47	0	72	0	334	406	864
Cobalt chloride*	0.05	38	0	0	0	37	37	97
Strontium chloride	0.05	53	4	54	0	403	461	870
Ferrous chloride	0.05	63	10	35	0	326	371	589
Ferric chloride	0.05	54	1	60	0	404	465	861
Nickel chloride*	0.05	33	1	0	0	56	57	173
Zinc chloride	0.05	40	1	27	0	123	151	378
Antimony trichloride	0.05	53	7	2	15	161	185	349
Barium chloride	0.05	52	0	10	0	328	338	650
Hydrogen chloride	0.05	54	84	227	0	15	326	604
Checks	.....	125	22	195	1	220	438	350

* Application toxic.

It is evident from table 5 that the chlorides have a decided stimulating effect on the formation of nodules. In seventeen cases out of the twenty-two in which the chlorides were applied, the number of nodules was greater per 100 plants than when no chlorides were applied to the soil (fig. 82). In three of the five cases in which the nodules were less than in the case of the check plants, the applications of the chlorides were toxic to the plants. In a preliminary experiment in which these three chlorides were applied in amounts not toxic, a stimulating effect was noted. With ammonium chloride there seems to be an inhibitory effect. This compound will be given further consideration later (table 8, page 390).

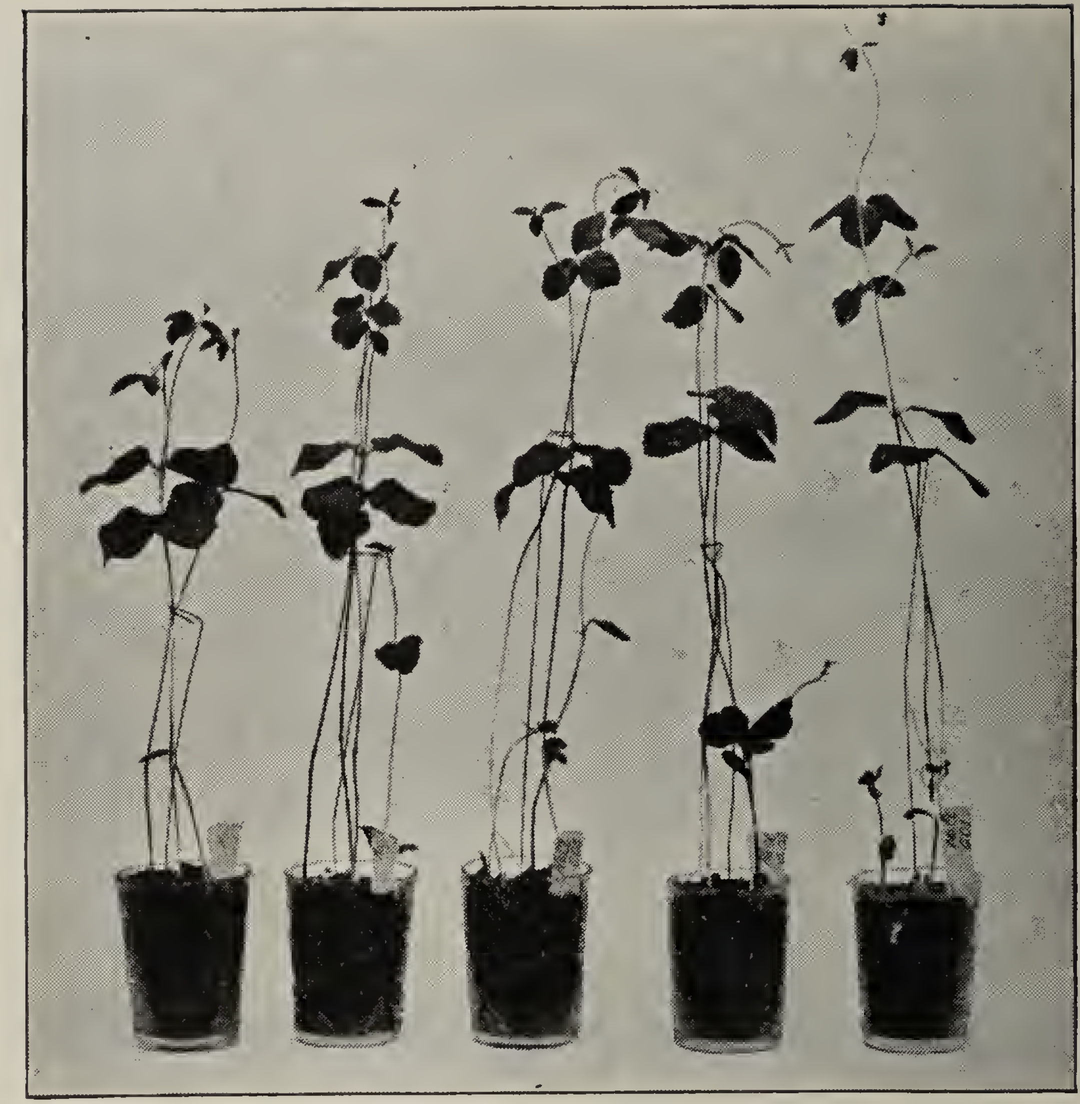

Fig. 83. PLANTS GROWN WITH SODIUM CHLORIDE

From left to right, plants grown with 0.2, 0.1, 0.05, 0.02, and 0.01 gram of sodium chloride, respectively, in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

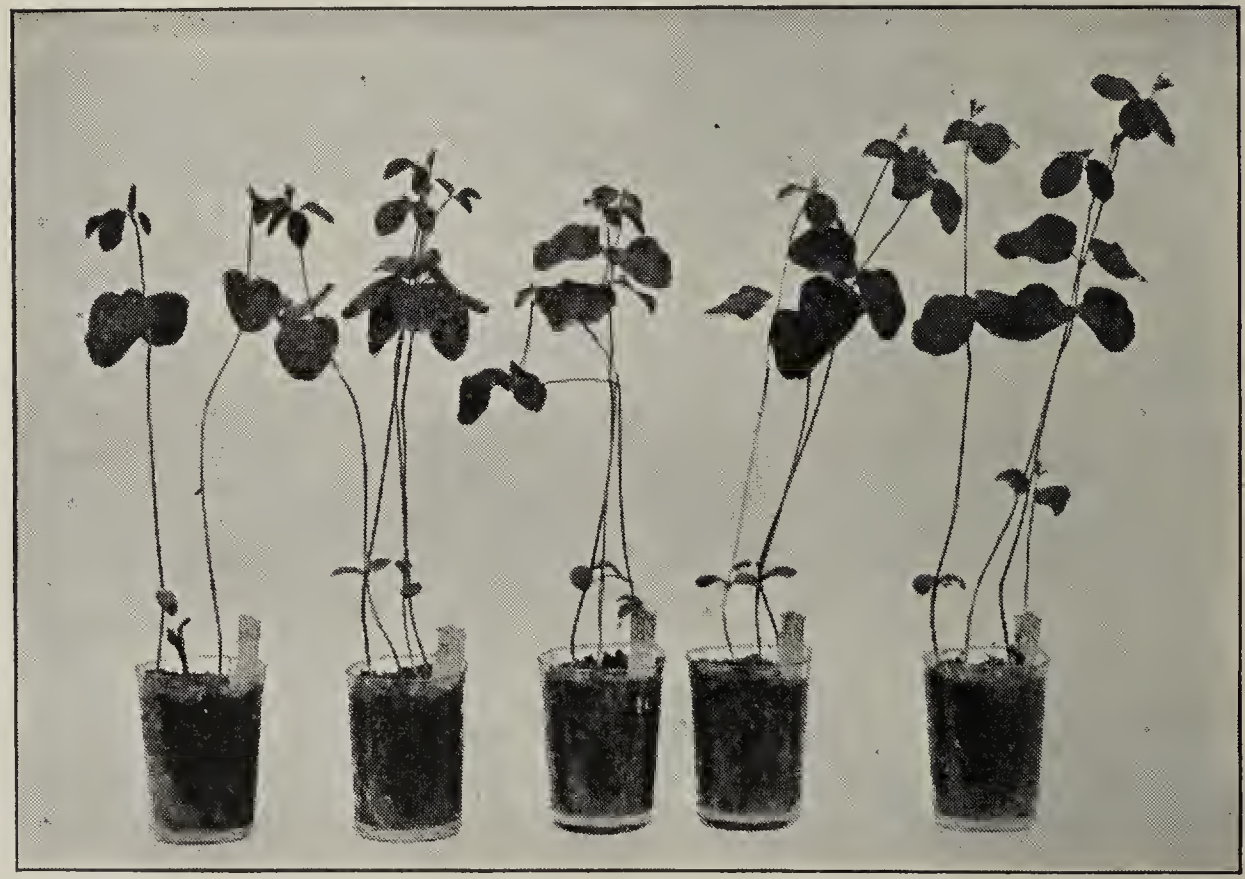

Fig. 84. PLANTS GROWN WITH STRONTIUM CHLORIDE

From left to right, plants grown with 0.2, 0.1, 0.05, 0.02, and 0.01 gram of strontium chloride, respectively, in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

In the case of some of these chlorides, and possibly with a majority of them, the high results obtained may be due in part to the presence of the base with which the chloride is combined. The results with calcium chloride would fall into this class. However, the consistently beneficial results with nearly all the chlorides, and the beneficial effect of hydrochloric acid in which there is no base, would tend to discredit the view that the base is a factor.

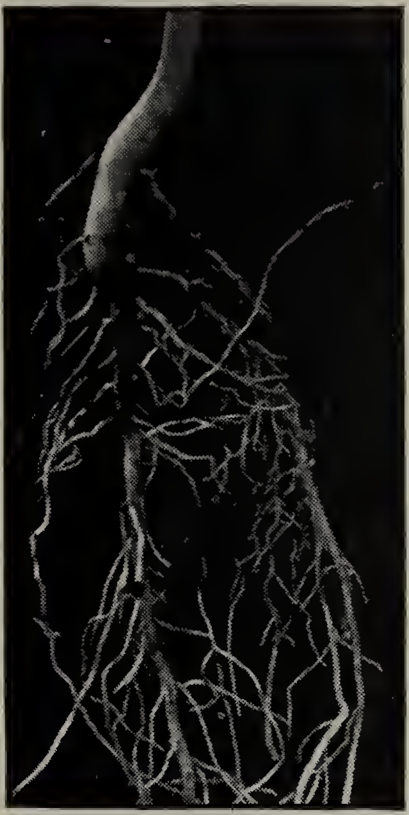

Fig. 85. ROOT OF PLANT GROWN WITH 0.01 GRAM OF POTASSIUM CHLORIDE. NATURAL SIZE

Plant grown in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

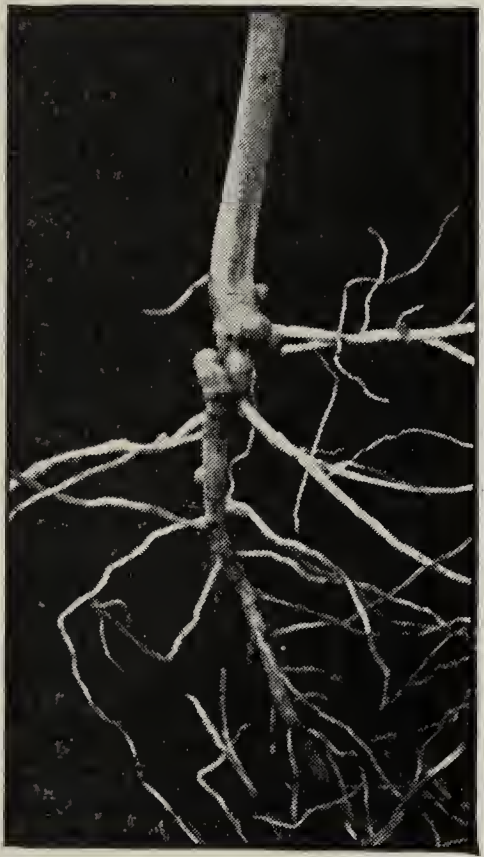

Fig. 87. ROOT OF PLANT GROWN WITH 0.01 GRAM OF STRONTIUM CHLORIDE. NATURAL SIZE

Plant grown in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

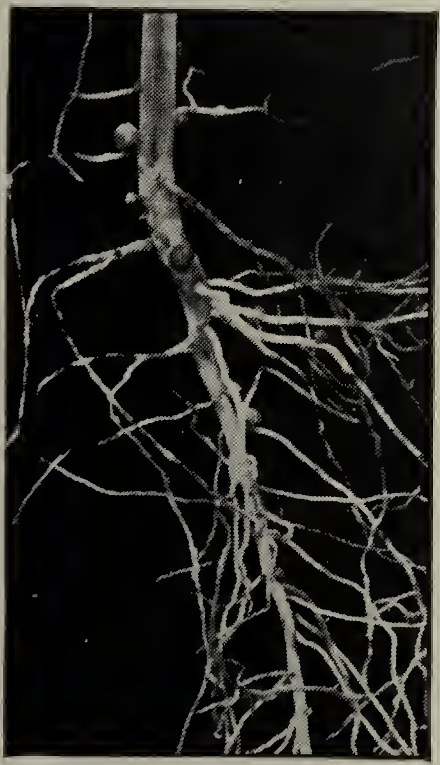

Fig. 86. ROOT OF PLANT GROWN WITH 0.01 GRAM OF SODIUM CHLORIDE. NATURAL SIZE

Plant grown in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

In a preliminary experiment in which the chlorides were applied in quantities sufficient to injure plant growth, they did not completely inhibit nodule formation. When 0.2 gram of copper chloride was applied, nodules were produced, while plants grown in the presence of 0.05 gram showed injury, which was evident by the appearance of brown spots on the roots. With cobalt chloride nodules were produced on the plant roots under applications of 0.1 gram, while the roots were injured by application of 0.05 gram per 208 grams of soil.

These results are quite in accord with those obtained by Laurent (1901), but are just the reverse of those obtained by Prucha (1915), who concluded that under the conditions of his experiments the chlorides of ammonium, potassium, and iron inhibit nodule formation in Canada field pea. These differences may be due to the use of a different host plant, but more probably they are due to differences in experimental procedure.

Sulfates

The influence of sulfates on the formation of nodules was tested in the greenhouse simultaneously with the study of the nitrates and the chlorides. The conditions for all three experiments were the same. The results with the sulfates are given in table 6:

TABLE 6. INFLUENCE OF SULFATES ON NODULE FORMATION
(In 208 grams of dry soil. Duration of experiment, 30 days)

Substance used	Quantity applied (grams)	Number of plants	Number of nodules on main roots		Number of nodules on other roots		Total number of nodules	Number per 100 plants
			Large	Small	Large	Small		
Sodium sulfate	0.05	65	11	46	2	53	112	172
Manganese sulfate	0.05	59	22	68	0	151	241	408
Magnesium sulfate	0.05	58	7	21	1	32	61	105
Calcium sulfate	2.00	61	12	101	0	53	166	272
Barium sulfate	2.00	63	16	93	1	92	202	321
Potassium sulfate	0.05	58	8	67	0	134	209	360
Zinc sulfate	0.05	61	8	67	0	104	179	293
Copper sulfate	0.05	61	2	11	0	48	61	100
Nickel sulfate*	0.05	52	0	9	16	79	104	200
Lithium sulfate	0.05	68	5	21	4	103	133	196
Aluminium sulfate	0.05	51	9	51	0	37	97	190
Strontium sulfate	2.00	66	6	117	1	89	213	323
Mercuric sulfate	0.50	44	0	9	0	15	24	55
Iron tersulfate†	0.05	56	9	39	1	99	148	264
Iron and ammonium sulfate	0.05	65	0	47	0	132	179	275
Ammonium sulfate	0.05	60	1	12	0	26	39	65
Calcium ethyl sulfate	0.05	53	64	171	11	195	441	832
Aluminium and ammonium sulfate	0.05	62	19	47	0	273	339	547
Chromium and potassium sulfate	0.05	70	13	46	2	247	308	440
Aluminium and potassium sulfate	0.05	58	39	79	0	278	396	683
Quinine sulfate	0.05	61	32	57	0	273	362	593
Checks	.....	125	22	195	1	220	438	350

* Roots show slight toxic effect from salt.
† This is iron *tersulfate*, not iron *persulfate*.

From these data it seems that the sulfates have a harmful effect on nodule formation. Of the twenty-one sulfates tested, fourteen show a reduction in nodule formation. Of these fourteen, mercuric sulfate and ammonium sulfate show the greatest depressing effect. Plants grown in the presence of 0.05 gram of potassium sulfate show 10 more nodules per 100 plants than do the checks, which is well within the normal variation. Those grown under the influence of manganese sulfate show 58 more nodules per 100 plants than do the checks. It would hardly seem that this is due to normal variation, but rather to the apparent stimulation of root growth by manganese, thus making possible a greater chance for infection. With calcium ethyl sulfate it is probable that the calcium, and perhaps the ethyl part of the compound, may have a beneficial influence on nodule formation. A further discussion of the calcium compounds is given on page 391. The aluminium and ammonium sulfate and the chromium and potassium sulfate have a noticeable stimulating effect. This was noted also with aluminium when applied as a nitrate, in which case the number of nodules per 100 plants was equal to or greater than the number per 100 plants of the check (table 3). Quinine sulfate increased the number of nodules from 350 per 100 plants, as shown by the checks, to 593. Undoubtedly the last-named result was due to the presence of the alkaloidal radical. In a preliminary test with caffein and amygdalin a stimulating effect was noted.

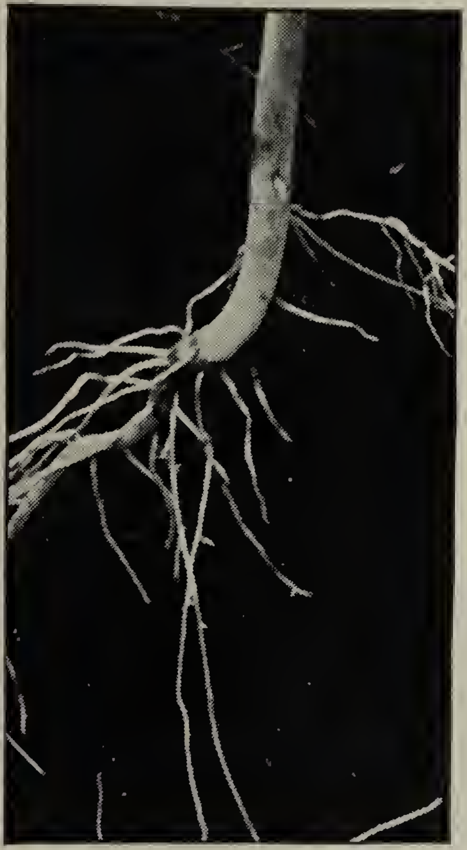

FIG. 88. ROOT OF PLANT GROWN WITH 0.01 GRAM OF SODIUM SULFATE. NATURAL SIZE

Plant grown in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

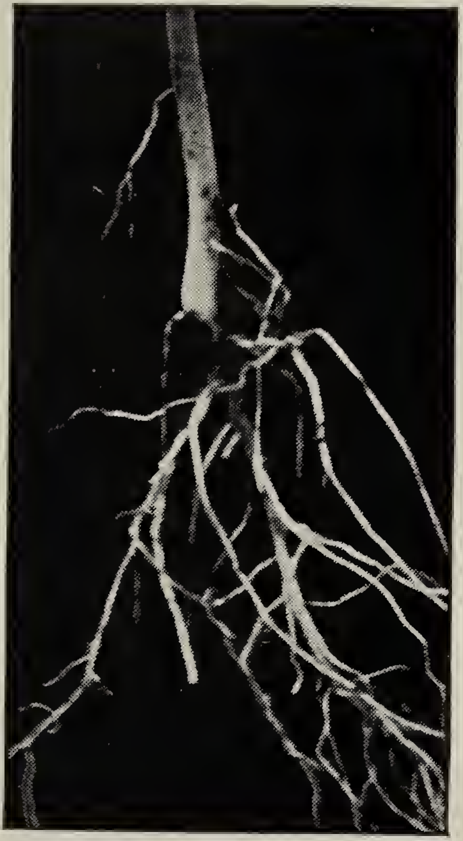

FIG. 89. ROOT OF PLANT GROWN WITH 0.01 GRAM OF POTASSIUM SULFATE. NATURAL SIZE

Plant grown in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

Phosphates

The influence of phosphates on nodule formation was tested simultaneously with that of the nitrates. The results are shown in table 7.

The data show conclusively that under these conditions phosphates increase the formation of nodules. In every case in which phosphates were applied, save that of disodium phosphate, the number of nodules per 100 plants was greater than with the check. The lower results with the disodium phosphate would seem to be due to the addition of a greater quantity of sodium, since the application of the monosodium phosphate more than doubled the number of nodules. The same relation holds with the di- and mono-potassium salts, altho the difference is not so marked.

TABLE 7. INFLUENCE OF PHOSPHATES ON NODULE FORMATION
(In 208 grams of dry soil. Duration of experiment, 30 days)

Substance used	Quantity applied (grams)	Number of plants	Number of nodules on main roots		Number of nodules on other roots		Total number of nodules	Number per 100 plants
			Large	Small	Large	Small		
Monosodium phosphate	0.1	50	28	65	0	294	387	774
Ferric phosphate......	0.1	64	38	70	3	260	371	580
Phosphoric acid.......	0.1	54	15	67	2	200	284	526
Monopotassium phosphate..............	0.1	63	7	159	0	237	403	640
Dipotassium phosphate.	0.1	48	10	128	0	115	253	527
Disodium phosphate...	0.1	54	8	96	0	54	158	293
Ammonium phosphate.	0.1	56	7	165	5	75	252	450
Magnesium phosphate.	0.5	57	35	237	0	91	363	637
Tricalcium phosphate..	0.5	59	18	137	0	69	224	380
Monocalcium phosphate	0.1	57	10	213	0	115	338	593
Dicalcium phosphate...	1.0	62	7	157	0	66	230	371
Checks..............	.....	125	22	195	1	220	438	350

Ammonia-containing or ammonia-producing compounds

The test to determine the influence of ammonia-containing or ammonia-producing compounds on nodule formation was made simultaneously with that of the nitrates. The results are given in table 8:

TABLE 8. INFLUENCE OF AMMONIA-CONTAINING OR AMMONIA-PRODUCING COMPOUNDS ON NODULE FORMATION
(In 208 grams of dry soil. Duration of experiment, 30 days)

Substance used	Quantity applied (grams)	Number of plants	Number of nodules on main roots		Number of nodules on other roots		Total number of nodules	Number per 100 plants
			Large	Small	Large	Small		
Ammonium sulfate....	0.05	60	1	12	0	26	39	65
Ammonium carbonate..	0.05	48	5	118	0	43	166	346
Ammonium nitrate....	0.1	49	0	0	0	4	4	8
Aluminium and ammonium sulfate........	0.05	62	19	47	0	273	339	547
Ammonium chloride...	0.05	39	0	19	0	29	48	123
Ammonium phosphate.	0.1	56	7	165	5	75	252	450
Dried blood...........	1.0	55	11	177	0	8	196	356
Witte's peptone.......	0.5	57	0	162	0	9	171	300
Ammonium hydroxide..	0.05	50	16	130	0	3	149	298
Checks..............	.....	125	22	195	1	220	438	350

From these data it is evident that certain ammonia-containing compounds materially reduce the formation of nodules. Ammonium nitrate under these conditions depressed nodule formation from 350 per 100 plants, as shown by the checks, to 8 per 100 plants. Ammonium sulfate reduced the number from 350 to 65 per 100 plants. Ammonium chloride, ammonium hydroxide, and Witte's peptone also were effective in reducing the number of nodules. In this test dried blood shows no effect; in a previous test 2 grams per 208 grams of soil completely inhibited nodule formation.

A comparison between treatments of ammonium hydroxide and of hydrogen chloride (table 5), and no treatment, shows that the ammonia reduced the number of nodules 52 per 100 plants below the check, while the hydrogen chloride increased the number 254 per 100 plants over the check. All plants were grown under the same conditions.

Not all the applied compounds that contained ammonia, however, depressed nodule formation. Among those that did not were aluminium and ammonium sulfate, and ammonium phosphate. This would indicate that there may be a neutralizing effect on nodule formation with two substances, one of which will stimulate and the other retard nodule formation. This is shown by the following comparison of the data obtained from the application of certain salts:

	Quantity applied	Nodules per 100 plants
Ammonium chloride	0.05 gram	123
Ammonium nitrate	0.1 gram	8
Aluminium chloride	0.05 gram	638
Check	....	350

These data indicate that where the anion and the cation in the same compound reduce the formation of nodules, the number of nodules per 100 plants is considerably smaller than where either one of the ions is combined with an element that is stimulative in effect. This is shown by ammonium nitrate. Here both the anion and the cation reduce nodule formation, but when the nitrate is replaced by the chloride, which is stimulative in effect, the number of nodules per 100 plants approaches more nearly that of the checks. Other comparisons could be made between calcium oxid, calcium sulfate, calcium chloride, and calcium nitrate (table 9). It is believed that if the right concentrations of these substances were used, this neutralizing effect could be made more pronounced.

Calcium-containing compounds

A test of the lime requirement of this Volusia silt loam according to the Veitch method shows that about 1100 pounds of calcium oxid per

TABLE 9. INFLUENCE OF CALCIUM-CONTAINING COMPOUNDS ON NODULE FORMATION

(In 208 grams of dry soil. Duration of experiment, 30 days)

Substance used	Quantity applied (grams)	Number of plants	Number of nodules on main roots		Number of nodules on other roots		Total number of nodules	Number per 100 plants
			Large	Small	Large	Small		
Calcium oxid	0.2	53	125	454	0	95	674	1,272
Calcium hydrate	1.0	61	13	249	0	205	467	766
Calcium sulfate	2.0	61	12	101	0	53	166	272
Calcium chloride	0.05	50	3	19	6	492	520	1,040
Tricalcium phosphate	0.5	59	18	137	0	69	224	380
Calcium ethyl sulfate	0.05	53	64	171	11	195	441	832
Calcium nitrate	0.1	63	0	5	0	80	85	135
Calcium carbonate	1.0	58	4	231	0	168	403	695
Calcium saccharate	0.7	56	113	213	2	353	681	1,216
Checks	.....	125	22	195	1	220	438	350

8,000,000 pounds of soil is necessary to neutralize it. One would expect, therefore, that an application of this material would stimulate nodule formation. The results on nodule formation of such a treatment, along with those from some other calcium-containing compounds, are presented in table 9.

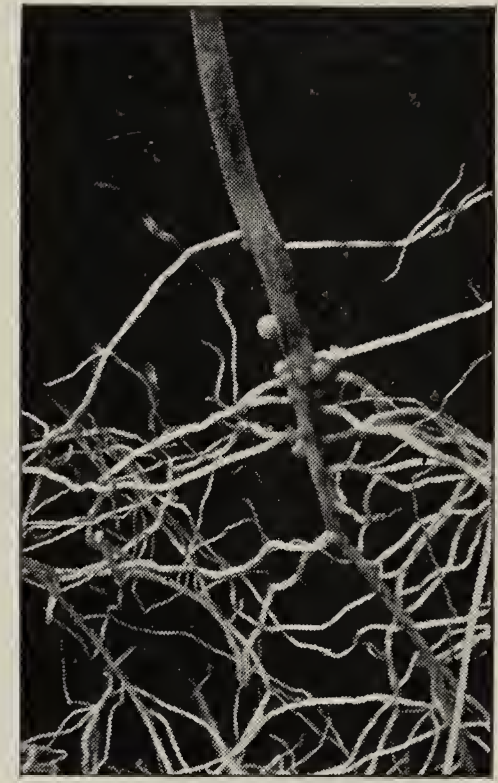

FIG. 90. ROOT OF PLANT GROWN WITH 0.2 GRAM OF CALCIUM OXID. NATURAL SIZE

Plants grown in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

The striking fact shown in this table is that certain calcium-containing compounds produce exceptionally favorable conditions for the development of nodules. First among these is calcium oxid (fig. 90). This compound gave the greatest stimulating effect of all the calcium-containing substances. It produced not only an increase in nodules, but also a change in their location on the root system. Of the 1272 nodules per 100 plants, 1092 were on the main root; and of these 1092, 236 were more than one millimeter in diameter. Calcium saccharate (fig. 91) is next in importance, giving 1216 nodules per 100 plants, and calcium chloride follows with 1040 nodules per 100 plants. As in the case of the oxid, these compounds have induced a greater number of nodules on the main root than have other non-calcium materials already discussed. The low results with calcium sulfate and calcium nitrate are undoubtedly due to the neutralizing effect of the material with which the calcium is combined.

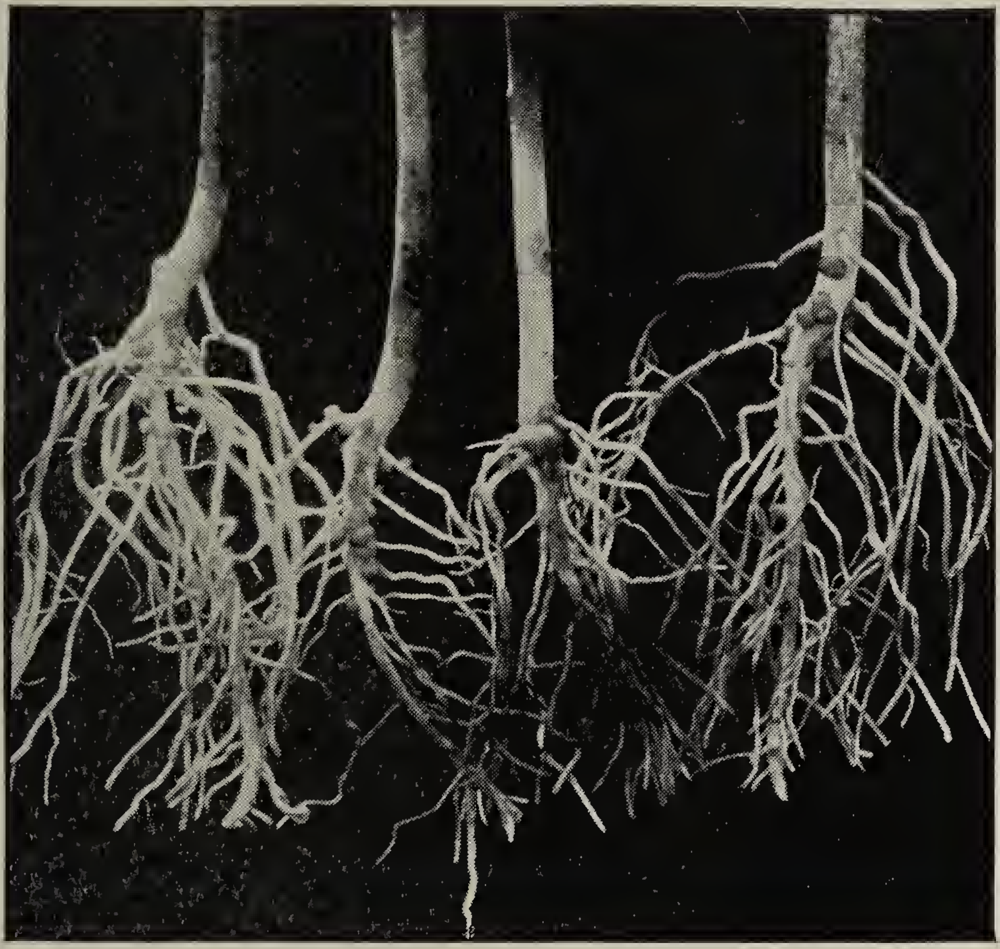

FIG. 91. ROOTS OF PLANTS GROWN WITH 0.75 GRAM OF CALCIUM SACCHARATE. NATURAL SIZE

Plants grown in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

Carbonates

Since carbonated water is nearly always found in the soil, it was thought well to ascertain what effect it might have on nodule formation. Data bearing on this point are presented in table 10:

TABLE 10. EFFECT OF CARBONATES ON NODULE FORMATION
(In 208 grams of dry soil. Duration of experiment, 30 days)

Substance used	Quantity applied (grams)	Number of plants	Number of nodules on main roots		Number of nodules on other roots		Total number of nodules	Number per 100 plants
			Large	Small	Large	Small		
Calcium carbonate.....	1.0	58	4	231	0	168	403	695
Barium carbonate.....	1.0	61	7	225	0	97	329	539
Ammonium carbonate..	0.05	48	5	118	0	43	166	346
Sodium bicarbonate....	0.1	46	11	90	0	100	201	437
Sodium carbonate.....	0.1	48	6	132	0	64	202	421
Checks...............	.....	125	22	195	1	220	438	350

It will be noted that in most cases the plants grown under the influence of the carbonates have more nodules per 100 plants than do the checks. However, if the influence of the alkaline radical with which the carbonate is combined were eliminated, this result would not be so apparent. From the data presented it cannot be said that the carbonate part of the compound has any influence on the formation of nodules.

Various carbon compounds

Various carbon compounds were applied to the soil and the effect on nodule formation was noted. It was necessary to apply the compound in rather excessive quantities in order to have it, or compounds resulting from its application, remain in the soil during the experimental period. Altho no tests were made to determine the length of time the compounds remained in the soil, it is believed that the applications were sufficient to permit them to continue in the soil during the infection period. The check plants in this case were those used in the experiments already described, and were grown at the same time with the plants to which the carbon compounds were applied. The results of these tests are given in table 11:

TABLE 11. INFLUENCE OF VARIOUS CARBON COMPOUNDS ON NODULE FORMATION

(In 208 grams of dry soil. Duration of experiment, 30 days)

Substance used	Quantity applied (grams)	Number of plants	Number of nodules on main roots		Number of nodules on other roots		Total number of nodules	Number per 100 plants
			Large	Small	Large	Small		
Glucose	2.0	59	29	78	0	100	207	351
Maltose	2.0	50	58	122	0	105	285	570
Fructose	2.0	58	110	296	0	149	555	957
Glycerin	1.0	64	122	241	0	21	384	600
Lactose	2.0	53	128	185	0	13	326	615
Saccharose	2.0	51	72	137	0	33	242	475
Starch	4.0	45	149	263	0	134	546	1,213
Oxalic acid	0.5	47	100	143	0	92	335	713
Lactic acid	0.5	63	88	319	0	104	511	811
Citric acid	0.5	57	86	262	0	108	456	800
Sodium tartrate	0.02	52	59	100	0	158	317	610
Potassium tartrate	0.02	55	63	290	0	244	597	1,085
Potassium citrate	0.02	58	49	261	0	38	348	600
Caffein	0.03	50	46	302	0	53	401	802
Calcium saccharate	0.7	56	113	213	2	353	681	1,216
Cumarin	0.03	23	33	148	0	32	213	926
Checks	....	125	22	195	1	220	438	350

The influence of carbon compounds on the formation of nodules is readily seen from table 11. Without exception, the number of nodules per 100 plants was greater where the soil was treated with carbon compounds than was the case with the checks. The three compounds giving the best results were calcium saccharate, starch, and potassium tartrate (fig. 92), in the order given. These three produced more than 1000 nodules per 100 plants, while the checks produced only 350 nodules. It is important to note also the number of nodules on the main roots in these cases, and their size in comparison with those of the checks. Of the 1213 nodules per 100 plants produced under the influence of starch, 916 were on the main root; and of these 916, 331 were more than one millimeter in diameter — only 19 less than the total number of nodules found on the checks.

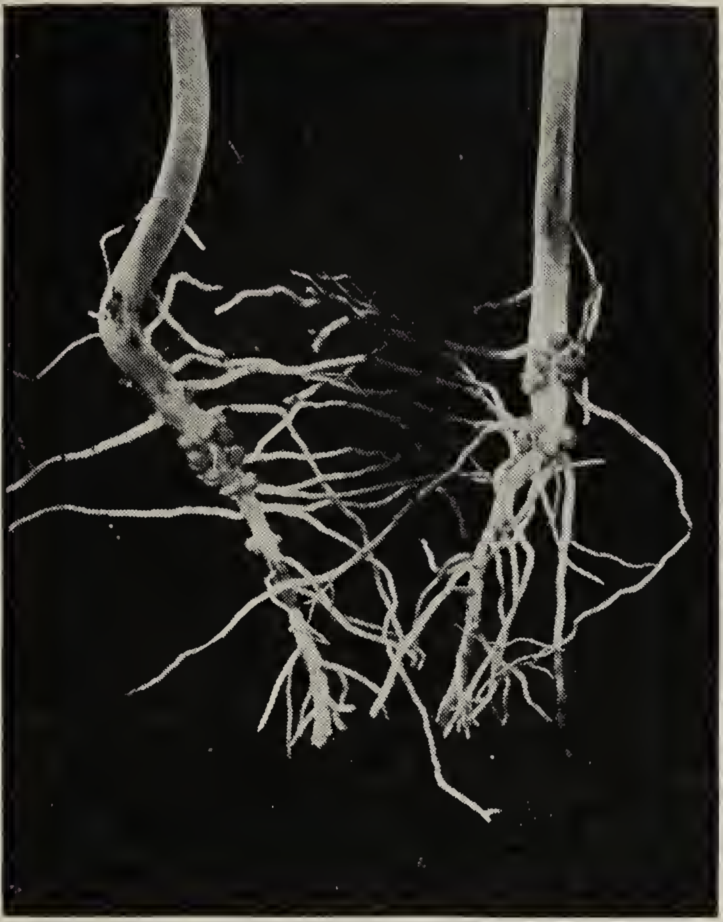

FIG. 92. ROOTS OF PLANTS GROWN WITH 0.02 GRAM OF POTASSIUM TARTRATE. NATURAL SIZE

Plants grown in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

Six other substances also more than doubled the production of nodules. These were fructose (fig. 93), with 957 nodules per 100 plants; oxalic acid, with 713; lactic acid, with 811; citric acid, with 800; caffein, with 802; and cumarin, with 926. These substances likewise produced a greater number of nodules on the main roots than on the secondary roots. The checks were about equally divided in this respect. These results indicate that the carbonaceous material was assimilated by the host plant and that this assimilation resulted in better nutrition — a factor which Vines believed to favor nodule production.

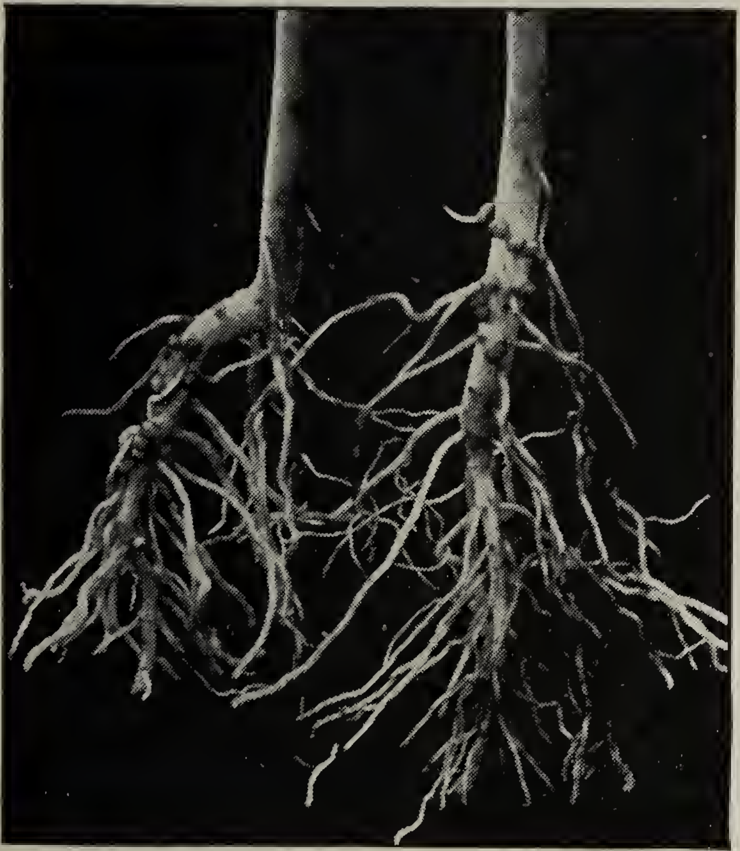

FIG. 93. ROOTS OF PLANTS GROWN WITH 2 GRAMS OF FRUCTOSE. NATURAL SIZE

Plants grown in 208 grams of soil; moisture content, 35 per cent of dry weight of soil

Variation of soil moisture

A test of the effect of moisture on nodule formation was conducted, using Volusia silt loam soil and adding to it the amount of distilled water necessary to give it the desired moisture content, which ranged from 25 to 75 per cent of the dry weight of the soil. Soil cultures were set up in the usual manner and five or six soybean plantlets were placed in each. The results are given in table 12:

TABLE 12. Effect of Moisture on the Formation of Nodules
(Soil cultures. Duration of experiment, 17 days)

Per cent of moisture	Number of plants	Number of nodules	Number of nodules per 100 plants
25	30	1	3
35	26	50	192
45	31	148	477
55	30	242	807
65*	34	408	1,200
75*	28	394	1,407

* With a moisture content of 65 and 75 per cent, free water stood above the soil in the containers.

The figures in table 12 show that as the moisture is increased the number of nodules is increased. This may be explained in several ways. The two most probable explanations are: (1) the greater the water content, the better is the opportunity for infection; or (2) the greater the water content, the more dilute is the soluble substance in the soil which may have an inhibitory effect on nodule formation. However, the presence of large amounts of moisture may result in a modification of the roots, the root hairs, or possibly the protoplasmic activities of the bacteria.

Moore (1905), in discussing this subject, says the effect of moisture is probably a physical one. Thru it the bacteria have a better opportunity to come in contact with the roots, and as a result a greater number of infections occur.

Water cultures

In this part of the work it was the intention to repeat in water culture, as far as possible, the work that had been done with soil. In order, therefore, to have no substances present other than such as would come from the container or from the seed, distilled water was used. Cylinders were employed, each containing 4700 cubic centimeters of water, to which was added the salt or salts to be tested. For each container ten plantlets were used. These were supported by paraffin paper covers, in such a manner that their roots could extend thru openings in the covers into the water. Growth was permitted for from four to six weeks.

Since it was shown by Prucha (1915) that nodules were not developed on Canada field pea in the absence of any one of the essential elements except nitrogen when he used the salts of Pfeffer's nutrient solution in six liters of water, it was decided to repeat this experiment, using soybeans instead of the peas. Accordingly Pfeffer's solution was made as follows:

Calcium nitrate	4 grams
Potassium nitrate	1 gram
Magnesium sulfate	1 gram
Monopotassium phosphate	1 gram
Potassium chloride	0.5 gram
Ferric chloride	0.005 gram
Water to make	6 liters

Pfeffer's solution with salts in various combinations

In making the tests in Pfeffer's solution with salts in various combinations, the full strength, and fifty-three of the possible sixty-three combinations, aside from the distilled water alone, were used. A list of these solutions is given on pages 402 and 403.

Careful examination of the roots was made after the treatment, and any tubercle-like swellings resembling nodules were sectioned and examined microscopically. Not a single nodule was observed on any plant root grown in any of the solutions. Many of the solutions employed permitted good growth, while some were so toxic that the plants scarcely remained alive.

Plants grown in tap water at the same time as those grown in Pfeffer's solution developed luxuriantly without the addition of any chemicals, and produced nodules abundantly in fifteen days. It was assumed that possibly the concentration of the solution was not favorable to nodule formation or that the distilled water was the inhibiting factor.

Pfeffer's solution of various strengths

The results of the preceding experiment led to a series of experiments in which the salts of Pfeffer's solution were again used in distilled water. The concentrations, however, differed from those in the preceding experiment. They were 8, 4, 3, 2, 1, 1/2, 1/4, 1/8, 1/16, and 1/32, of the concentration of the full-strength solution. These were prepared on September 3, and on October 7 the roots were examined for nodules.

In only two of these concentrations were nodules produced. In the double strength there was a single plant which had two nodules, both below the water line. The other case was in the 1/4 concentration, in which there was one nodule slightly above the water line.

Pfeffer's solution in the absence of nitrates

As the concentrations used in the preceding experiment were not favorable to nodule formation, it was decided to repeat this work leaving out the nitrates. Accordingly the following strengths of Pfeffer's solution were used: 8, 4, 2, 1, 1/4, 1/8, 1/16, 1/32. Potassium chloride and calcium chloride in molecular equivalents were substituted for the nitrates.

The plants grew normally in all the concentrations except the highest. No nodules were found in any of the concentrations greater than 1/4 strength. In the 1/4-strength solution and in all the lower concentrations there were nodules produced, but in no case were they as numerous as in the tap-water cultures which had been prepared as a means of checking the time factor in nodule development.

Magnesium sulfate in distilled water

The results obtained with Pfeffer's solution in various concentrations led to a test of these various salts individually in distilled water. The containers were 800-cubic-centimeter cylinders and were prepared as described on page 374. The amounts of magnesium sulfate in grams per liter of water were as follows: 2, 1, 1/2, 1/4, 1/8.

After standing for thirty-six days in the greenhouse the plants were examined for the presence of nodules. The plants had made a fair growth. The roots were short in the two strongest concentrations. No nodules were observed on any of the roots.

Monopotassium phosphate

This experiment is a parallel of the one with magnesium sulfate. The phosphate was used in concentrations of 2, 1, 1/2, 1/4, 1/8, grams per liter of water.

The plants were examined thirty-eight days after inoculation. Those in the concentrations greater than 1/4 gram per liter of water were dead. The other concentrations were not toxic to any noticeable extent. The plants were 12 inches tall. No nodules were evident.

Distilled water shaken with carbon black

The difficulties encountered in producing nodules in distilled water led to the treatment of the water with carbon black. This was done by shaking the distilled water for fifteen minutes with 2 grams of petroleum carbon black per liter of water. After filtering, the water was used in tumblers alone and in combination with certain chemical substances that were known to have an influence on the formation of nodules when added to soil. The contents of the tumblers were inoculated with one cubic centimeter of a water suspension of *Bacillus radicicola*. In table 13 the results are compared with data obtained under identically the same conditions with plants grown in tap water:

TABLE 13. NODULE FORMATION IN DISTILLED WATER SHAKEN WITH CARBON BLACK, AS COMPARED WITH TAP WATER*

Substance used	Concentration (given as molecular weight of compound in 1 liter of water)											
	Distilled water						Tap water					
	1/2500	1/3500	1/5000	1/10,000	1/50,000	1/100,000	1/2500	1/3500	1/5000	1/10,000	1/50,000	1/100,000
Zinc nitrate	—t	—t	—t	—t	—t	+	—t	—t	—t	—t	—t	—t
Ammonium nitrate	—	—	—	+	+	+	—	—	—	—	+	—
Potassium nitrate	—	—	—	—	+	+	+	—	+	+	+	—
Calcium nitrate	+	+	+	—	+	+	+	+	+	+	+	+
Sodium nitrate	+	+	+	+	—	+	+	+	+	+	+	+
Strontium nitrate	—t	—t	—	+	+	+	—	—	+	+	+	+
Sodium chloride	+	—	+	+	+	+	—	+	+	+	+	+
Calcium chloride	—	+	+	+	+	+	—	+	+	+	+	+
Aluminium chloride	—t	—t	—t	+t	+	—	—t	—t	+t	+	+	+
Potassium chloride	—	—	—	+	—	+	—	+	+	+	+	+
Zinc chloride	—t	—t	—t	—t	+	—	—t	—t	—t	—t	+	+
Strontium chloride	—t	—t	—	+	+	—	+	+	+	+	+	+
Potassium sulfate	—t	—t	+	+	+	+	+	—	+	+	+	+
Ammonium sulfate	—t	—t	—t	—t	—t	—t	—	—	+	+	+	+
Aluminium sulfate	—t	—t	—t	—t	—	—	—	—	—	+	+	+
Strontium sulfate	—t	—t	—t	—t	—t	+	—	—	+	+	+	+
Sodium sulfate	—t	—t	+	+	+	—	—	—	+	+	+	+
Zinc sulfate	—t	—t	—t	—t	—t	+	—t	—t	—t	—t	—t	+
Checks	Only 2 nodules on 18 plants.						+	+	+	+	+	+

* + indicates nodules present; — indicates no nodules; "t" indicates concentration toxic to roots.

The results obtained with the distilled water shaken with carbon black without the addition of any substance are for the most part negative. Only two nodules were found on eighteen plants, and these were on one plant.

It should be noted that each nitrate changed the condition in the distilled water treated with carbon black to such an extent that nodules were produced, and also that as the concentration of the nitrate increased there was a tendency toward prevention of nodule production. Calcium nitrate and sodium nitrate seem to be less inhibitory in their effect than the other nitrates used. In tap water the nitrates seem to produce about the same results.

Sodium and calcium chloride and sodium and potassium sulfate also appear to react favorably to nodule formation in the treated distilled water. With the sulfates this favorable action is present in as low a concentration as 1/50,000 molecular solution, and extends to concentrations that appear toxic to the plant roots. Their action is not so pronounced, however, as that of the chlorides.

VITALITY OF BACILLUS RADICICOLA OF SOYBEAN UNDER CULTURAL CONDITIONS

In previously reported experiments it was shown that the formation of nodules was completely checked when a nitrate or a sulfate was applied to soil in sufficient quantities, even tho the application was far below the amount necessary to produce injury to the plants. The same effect was observed in water cultures. The question that immediately presented itself was, What was the cause for such inhibitory effects? Did these compounds destroy the organism, or was some other factor operating? In order to obtain data on this subject the soil and water cultures employed in the experiments already reported were used as a basis for further study.

In soil cultures

In testing for the presence or the absence of the organism in those cases in which nodule formation was inhibited by the application of various substances, the following method was employed: At the time of examination of the roots for nodules, which was after fifty days, the culture vessels were tapped gently so that the soil and the roots would come out in a mass. This mass was broken open, and some of the soil (about 5 grams) from the center of the mass was taken on a sterile spatula. This soil was used as inoculating material for other sterilized tumblers which were partly filled with soil. These tumblers, after being inoculated, were planted with ten soybeans, watered, and left in the culture room. At the end of twenty days the roots were examined for nodules. The results, which are shown in table 14, were compared with checks grown under the same conditions.

The results indicate that the application of nitrates or sulfates to soil in quantities sufficient to prevent nodule formation does not destro the organism, for in most cases when brought into favorable condition the organisms were, from all tests, as efficient as the original culture or as those cultured organisms in the soil with the presence of a smaller amount of nitrate or sulfate. There are a few apparent exceptions to this statement, these being the nitrates of mercury, uranium, and nickel, and the sulfate of mercury. Why such results should be obtained with these compounds is not known. It is possible that these substances in the soil have a greater toxic effect than the other compounds, or that they react with the soil in some way to form a germicide and thus destroy the legume organism.

TABLE 14. INFLUENCE OF VARIOUS SALTS IN SOIL ON THE VITALITY OF BACILLUS RADICICOLA*

(Presence of organism determined at the end of 50 days by its ability to produce nodules. Duration of test, 20 days)

Substance used	Quantities applied in inhibiting concentrations, with results									
	Quantity applied	Organism	Quantity applied	Organism	Quantity applied	Organism	Quantity applied	Organism	Quantity applied	Organism
Cerium nitrate	1.0	—	0.5	—	0.2	+	.....	....	.....	.....
Lead nitrate	0.5	—	0	....	0.2	+	.....	....	.....	.....
Silver nitrate	0	....	.....	....	.....	....	0.05	—	.....	.....
Mercuric nitrate	1.0	—	0.5	—	0.2	—	.....	....	.....	.....
Ammonium nitrate	.....	....	0.5	—	0.1	+	.....	....	.....	.....
Calcium nitrate	1.0	+	.....	....	.....	....	.....	....	.....	.....
Zinc nitrate	.....	....	0.2	+	0.1	+	.....	....	.....	.....
Uranium nitrate	1.0	—	0.5	—	0.2	—	0.1	—	.....	.....
Sodium nitrate	1.0	—	0.5	+	0.2	+	0.1	+	.....	.....
Ferrous nitrate	.....	....	.....	....	0.2	+	.....	....	.....	.....
Barium nitrate	.....	....	0.5	+	0.2	—	.....	....	.....	.....
Potassium nitrate	.....	....	0.5	+	0.1	+	0.05	+	.....	.....
Nickel nitrate	.....	—	0.2	—	0.1	—	0.05	—	.....	.....
Magnesium nitrate	1.0	—	0.5	+	.....	....	.....	....	.....	.....
Strontium sulfate	5.0	+	2.0	+	0.5	—	.....	....	.....	.....
Copper sulfate	.....	....	0.1	—	.....	....	.....	....	.....	.....
Chromium and potassium sulfate	.....	....	0.5	—	0.2	—	0.1	—	0.05	+
Sodium sulfate	.....	....	0.5	....	.....	....	.....	....	.....	.....
Ferrous sulfate	0.02	+	0.1	+	0.05	+	0.02	+	0.01	+
Iron and ammonium sulfate	0.5	+	0.2	+	0.05	+	.....	....	.....	.....
Cobalt sulfate	0.05	+	.....	....	.....	....	.....	....	.....	.....
Manganese sulfate	0.2	+	0.1	+	.....	....	.....	....	.....	.....
Mercuric sulfate	1.0	—	0.25	—	0	....	.....	....	.....	.....
Ammonium sulfate	0.5	+	0.2	+	0.1	+	0.05	+	0.02	+
Zinc sulfate	0.2	+	0.05	+	0.01	+	0	....	.....	.....
Aluminium and potassium sulfate	0.5	+	0.05	+	.....	....	.....	....	.....	.....
Barium sulfate	10.0	+	5.0	+	2.0	+	.....	....	.....	.....
Aluminium sulfate	0.2	+	0.1	+	.....	....	.....	....	.....	.....
Magnesium sulfate	2.75	+	1.35	+	0.35	+	0.275	+	.....	.....
Aluminium and ammonium sulfate	0.5	+	0.1	+	.....	....	.....	....	.....	.....
Checks	18 tumblers. No nodules.									

* + indicates organism present; — indicates organism not present.

In water cultures

It has been shown that nodules are not produced in distilled water alone, nor, except in rare cases or in certain dilute concentrations, in distilled water to which the various salts of Pfeffer's solution have been added.

In order to test the ability of the organism to exist in these solutions without effecting inoculation, about 5 cubic centimeters of the liquid from the various containers was used as a source of inoculating material for seedling host plants. The organism had been placed in the solution from four to six weeks previous to this determination. The containers for these solutions were covered thruout the entire period with paraffin paper, so that there was but little opportunity for the solutions to become contaminated.

The salts or combinations of salts tested with respect to their influence on the vitality of the organism are listed in table 15. The plus or the minus sign indicates the efficiency or the inefficiency of the organism to effect inoculation after remaining in the salt solution for from four to six weeks. In all cases the reinoculated plants grew for twenty-one days before examination.

TABLE 15. VITALITY OF BACILLUS RADICICOLA AFTER REMAINING FROM FOUR TO SIX WEEKS IN DISTILLED WATER TO WHICH HAD BEEN ADDED THE SALTS OF PFEFFER'S SOLUTION IN VARIOUS DILUTIONS AND COMBINATIONS*

Substance used	Organism
Calcium nitrate	—
Potassium nitrate	+
Magnesium sulfate	+
Monopotassium phosphate	+
Potassium chloride	+
Ferric chloride	+
Calcium nitrate and potassium nitrate	+
Calcium nitrate and magnesium sulfate	+
Calcium nitrate and monopotassium phosphate	+
Calcium nitrate and potassium chloride	+
Calcium nitrate and ferric chloride	+
Potassium nitrate and magnesium sulfate	+
Potassium nitrate and monopotassium phosphate	—
Potassium nitrate and potassium chloride	+
Potassium nitrate and ferric chloride	+
Magnesium sulfate and monopotassium phosphate	—
Magnesium sulfate and potassium chloride	—
Magnesium sulfate and ferric chloride	+
Monopotassium phosphate and potassium chloride	+
Monopotassium phosphate and ferric chloride	—
Potassium chloride and ferric chloride	+
Calcium nitrate, potassium nitrate, and magnesium sulfate	+
Calcium nitrate, potassium nitrate, and monopotassium phosphate	+
Calcium nitrate, potassium nitrate, and potassium chloride	+
Potassium nitrate, magnesium sulfate, and monopotassium phosphate	—
Potassium nitrate, magnesium sulfate, and potassium chloride	+
Potassium nitrate, magnesium sulfate, and ferric chloride	+
Magnesium sulfate, monopotassium phosphate, and potassium chloride	+
Magnesium sulfate, monopotassium phosphate, and ferric chloride	+
Monopotassium phosphate, potassium chloride, and ferric chloride	+
Calcium nitrate, potassium nitrate, and ferric chloride	+
Calcium nitrate, potassium nitrate, magnesium sulfate, and monopotassium phosphate	+
Calcium nitrate, potassium nitrate, magnesium sulfate, and potassium chloride	+

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* + indicates organism present; — indicates organism not present.

TABLE 15 (*continued*)

Substance used	Organism
Calcium nitrate, potassium nitrate, magnesium sulfate, and ferric chloride	+
Potassium nitrate, magnesium sulfate, monopotassium phosphate, and potassium chloride	+
Potassium nitrate, magnesium sulfate, monopotassium phosphate, and ferric chloride	+
Calcium nitrate, potassium nitrate, magnesium sulfate, monopotassium phosphate, and potassium chloride	+
Potassium nitrate, magnesium sulfate, monopotassium phosphate, potassium chloride, and ferric chloride	+
Calcium nitrate, potassium chloride, and ferric chloride	+
Calcium nitrate, monopotassium phosphate, and potassium chloride	+
Calcium nitrate, magnesium sulfate, and monopotassium phosphate	+
Potassium nitrate, potassium chloride, and ferric chloride	+
Potassium nitrate, monopotassium phosphate, and potassium chloride	+
Magnesium sulfate, potassium chloride, and ferric chloride	+
Calcium nitrate, potassium nitrate, potassium chloride, and ferric chloride	+
Calcium nitrate, potassium nitrate, monopotassium phosphate, and potassium chloride	+
Calcium nitrate, monopotassium phosphate, potassium chloride, and ferric chloride	+
Calcium nitrate, magnesium sulfate, monopotassium phosphate, and potassium chloride	+
Calcium nitrate, potassium nitrate, potassium chloride, and ferric chloride	+
Pfeffer's solution 8 concentration	+
Pfeffer's solution 4 concentration	—
Pfeffer's solution 3 concentration	+
Pfeffer's solution 1 concentration	—
Pfeffer's solution 1/2 concentration	+
Pfeffer's solution 1/4 concentration	+
Pfeffer's solution 1/8 concentration	+
Pfeffer's solution 1/16 concentration	+
Pfeffer's solution 1/32 concentration	+
Pfeffer's solution minus the nitrates, which were replaced by chlorides in equivalent amounts	
8 concentration	+
4 concentration	—
2 concentration	—
1 concentration	—
1/2 concentration	—
1/4 concentration	+
1/8 concentration	+
1/16 concentration	—
1/32 concentration	+
Monopotassium phosphate in concentrations of	
2 grams per liter	+
1 gram per liter	+
1/2 gram per liter	+
1/4 gram per liter	+
1/8 gram per liter	—
Magnesium sulfate in concentrations of	
2 grams per liter	—
1 gram per liter	—
1/2 gram per liter	+
1/4 gram per liter	+
1/8 gram per liter	+
Total, 77. Organism present in 61 cases, not present in 16.	

It will be observed from this list that the organism retained its vitality in 61 out of 77 cases, and that no one particular salt was present in all the 16 solutions in which the organism was not found.

Conclusion

These results lead to the conclusion that there is evidence for the belief that the chemical nature of the salt solution is a factor in controlling nodule production. In all these cases the organism, tho still living in the soil or water culture, was not capable of inducing nodule formation.

TIME REQUIRED FOR INITIAL INFECTION

It is known that infection of the host plant by *Bacillus radicicola* takes place in a relatively short time, for plants that have been inoculated with a pure culture will show abundant nodule development within ten days if the conditions are right. Peirce (1902) showed that on bur clover the characteristic bending of the root hairs previous to nodule formation will occur in twenty-four hours after inoculation. But the exact time required for the organism to penetrate the host, so far as the writer knows, has never been determined. Experiments were therefore made to ascertain this point.

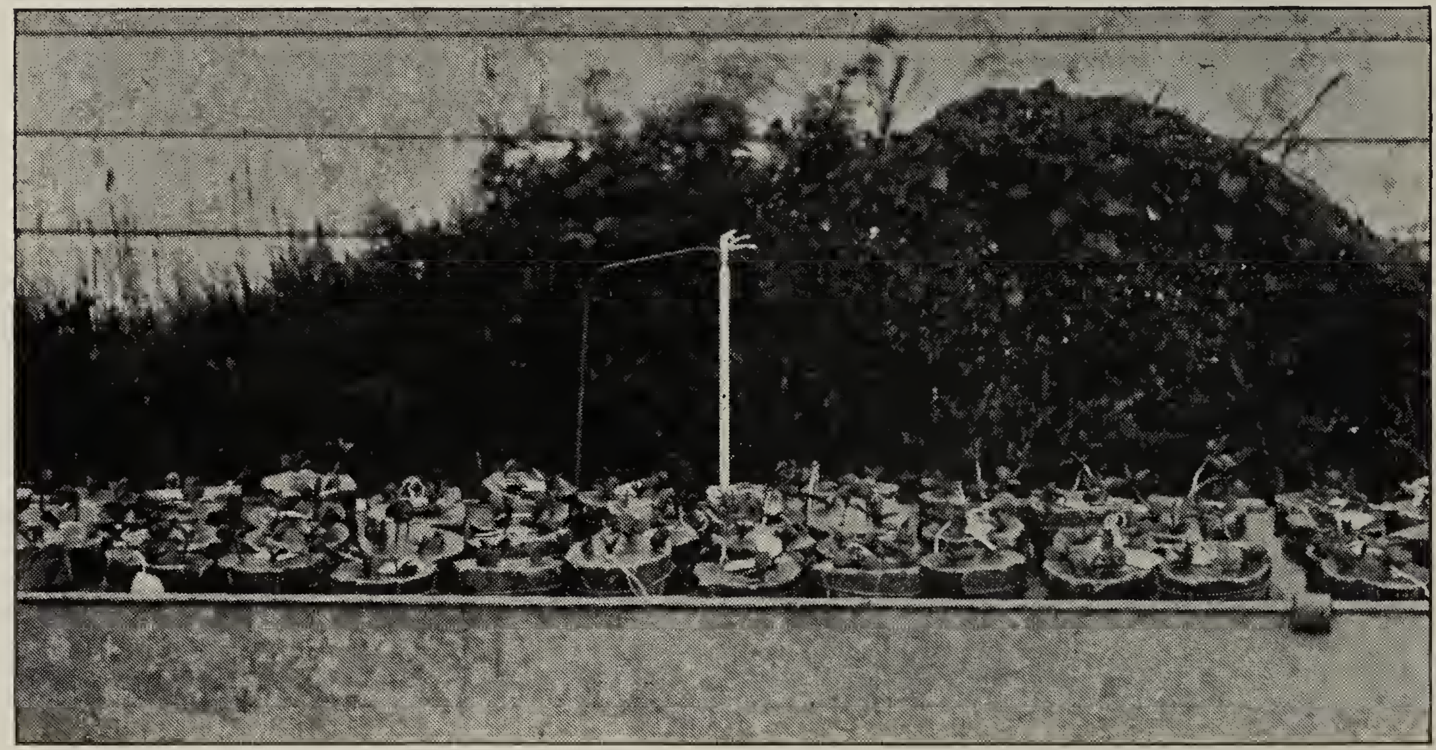

FIG. 94. METHOD OF TESTING FOR INITIAL PERIOD OF INFECTION, SHOWING SIZE OF PLANTS AT TIME OF TEST

Water cultures in tumblers of 250 cubic centimeters capacity were used. These cultures were set in water in a shallow pan and kept out of doors. Four soybean plantlets were inserted thru holes in the paper cover of each tumbler so that the roots were immersed. Water was run from the tap into the pan by means of a hose. Twenty-four hours later the contents of the tumblers were equally inoculated with a vigorously growing culture of *B. radicicola.* At certain intervals (as shown in table 16) two tumblers were removed from the pan and connected with siphons which carried fresh water into them, replacing the inoculated water. The rate of flow of the wash water was 250 cubic centimeters per 30 seconds, this being the volume of the tumbler. In all cases the siphons were kept running for a period not shorter than five days. After this washing the tumblers were returned to the pan, where a temperature of about 20° C. was being maintained. The contents of the tumblers were inoculated on June 29, 1914, and the roots were examined for nodules on July 14, 1914. The results are presented in table 16:

TABLE 16. TIME REQUIRED FOR INITIAL INFECTION

(Water culture, eight plants. Duration of experiment, 14 days. Temperature, 20° C.)

Duration of contact between roots and inoculated water	Length of time roots were washed with running water from siphon (days)	Number of nodules that developed on roots as result of treatment
No contact	6	0
A few seconds	6	1
(Minutes)		
5	5	0
10	5	0
15	5	1
20	5	0
25	5	1
30	5	0
35	5	1
40	5	0
45	5	1
(Hours)		
1	5	1
1¼	5	3
1⅔	5	0
2	5	13
2½	5	7
2¾	6	5
4	6	7
4⅔	6	19
5½	6	29
6½	6	14
10	6	23
12½	6	42
14	6	26
18	6	24
(Days)		
14	Not washed	11 tumblers, 1145 (or 208 per 8 plants)

From these data it is seen that infection occurred immediately, for washing did not remove all the organisms from the roots. The plant roots that were exposed for only a few seconds showed one nodule, and occasionally nodules were produced with the initial time of exposure under four and two-thirds hours. All nodules that were produced with an initial time of infection shorter than four and two-thirds hours appeared in the fork of the root system or in some place among the roots where the organisms would be protected from the water current of the siphon. The roots exposed for four and two-thirds hours before the siphon was started showed what might be called a general infection. By this is meant an infection of the root system in places freely exposed to the washing effect of the running water. It should be noted that there were not so many nodules produced at an exposure of eighteen hours as there were in cases in which the roots were not washed at all. This would be expected, for all infections that may occur do not necessarily occur in the first eighteen or twenty-four hours. In a previous determination to ascertain the time required for initial infection, in which the plants were considerably older when inoculated, general infection occurred with or after an exposure of five hours.

IS NODULE FORMATION ASSOCIATED WITH THE NITROGEN REQUIREMENT OF PLANTS?

The views of various investigators imply that nodule formation is associated with a demand on the part of the plant for nitrogen. This view is dependent on the fact that nitrogenous compounds, and particularly nitrates, depress or inhibit nodule formation, and it has therefore been assumed that plants having a sufficient supply of nitrogen abstain from the production of nodules. This view suggests an ability on the part of the plant to preferentially adapt itself with respect to its nitrogen requirements. Such a view is not tenable in the light of present knowledge of plants. Furthermore, the various sulfates depress or inhibit nodule formation just as effectively as do the nitrates. It would appear that the respective explanations for the inhibiting action of nitrogenous compounds and of various sulfates on nodule formation are similar in nature. As an effective answer to the older views, as well as to determine whether the influences of the nitrogenous compounds are mainly local in their effect, the following experiments were made.

Experiment 1

Thin-walled vessels were arranged side by side in pairs so that the roots of a single plant could be extended into the solutions in both containers. In order to have favorable conditions for nodule development, strontium chloride was added to one container in molecular concentration

1/5000. The other container received ammonium nitrate. The nitrate was varied in different containers, as is indicated in table 17. The root systems of young seedlings were divided, and one portion was extended into the nitrate solution and the other into the chloride solution. The volume of solution was the same for each half of the plant roots. After inoculating the contents of each container with a culture of *Bacillus radicicola* the plants were allowed to grow for fourteen days. This method offered to one-half of the root system all the nitrate that the plant could use, and permitted growth of a part of the root system in a solution containing only traces of nitrates. The results on nodule production are given in table 17:

TABLE 17. Nodule Production on Individual Plants with Roots Divided, Part being Placed in a Nitrate Solution and the Remainder in a Chloride Solution*

(Fourteen days after inoculation. Strontium chloride, molecular solution 1/5000)

Ammonium nitrate (molecular concentration)	Nodules on	
	Nitrate side	Chloride side
1/5000	+	+
1/3500	+	+
1/2500	+	+
1/1250	+	+
1/800	+	+
1/600	+	+
1/500	+	+
1/450	+	+
1/300	+	+
1/250	—	+
1/220	—	+
1/185	—	+
1/175	—	+

* + indicates nodules present; — indicates no nodules.

It is brought out clearly in table 17 that nodule development occurred in every instance on the roots that grew in the chloride solution. It is also shown that the remainder of the root system, which was grown in the nitrate solution, produced nodules up to and including molecular concentration 1/300, and that the roots in greater molecular concentration than 1/300 produced no nodules.

Experiment 2

Young plants were grown in water culture to which was added ammonium nitrate in molecular concentration 1/1200. When the plants were about eight to ten inches high, cotton was wrapped around each stem and twisted into a wick. This wick extended into a container holding a solution without nitrates. In a few days roots were produced which grew out into the cotton. When these roots appeared more nitrate was added to the water in which the primary root with its laterals was growing, until the concentration was molecular 1/250. This concentration is great enough to prevent nodule formation and still not great enough to noticeably injure plant growth. Both root systems were inoculated with *B. radicicola*, and after two weeks were examined for nodules.

The primary root and its laterals which were growing in the presence of the nitrate showed no nodule formation. The roots that were produced above the cotyledonary part in the cotton and subsequently inoculated, showed well-developed nodules.

Conclusion

The data from these experiments show that the effect of the nitrates in depressing nodule formation is at most only local in character, and that the plant does not exercise any preference of methods for obtaining nitrogen.

GENERAL DISCUSSION

The experiments described herein were undertaken in order to study the physiology of the causal organism of nodule formation on soybeans, and the factors influencing nodule development. The work was done under artificial conditions in the greenhouse and in the laboratory. The results obtained apply to this organism only, altho in many respects the data are in accord with those obtained by other investigators working with other strains of *Bacillus radicicola*. With the technique used it has been possible to demonstrate conclusively that the flagella of the soybean organism are peritrichous and that as many as four may be found. This peritrichous arrangement agrees with that found by De' Rossi (1907), Zipfel (1912), Kellerman (1912), and Prucha (1915), with the organism of other host plants. It would seem, therefore, that this character, as suggested by Kellerman and others, is uniform among the legume bacteria.

A review of the literature of the subject brings out very clearly the fact that nodule formation can be checked or stimulated, depending on the presence or the absence of certain salts and on the amount of moisture present. Additional light has been thrown on this point by extending the observations already made and by working under carefully controlled conditions. It is suggested that some of the discordant results reported in the literature are due to a lack of properly controlling many of the factors that bear directly or indirectly on nodule production. In this connection one may refer to the soil moisture. In these experiments, with an increase of moisture content from 35 to 45 per cent the nodule production was more than doubled (table 12, page 396), while with an increase from 45 to 55 per cent it was nearly doubled.

To the class of compounds including those that stimulate nodule formation belong the chlorides, the phosphates, the calcium-containing compounds, and certain organic carbon compounds. Vines (1888–89) and others have suggested that nodules are produced only when the conditions of nutrition are favorable. Other investigators claim that the organism derives from the host plant carbohydrate material for its energy, and is thus attracted, and that nodule development will not occur unless the host plant is doing active photosynthetic work. While these and other suggested explanations as to the cause of nodule production may be of importance, they do not appear entirely satisfactory. It would seem in this connection that the application of sugars, or of such a material as starch, which probably serves as a source of energy for the organism and possibly for the plant, would furnish more nearly ideal conditions for the development of the organism than are found in the tissue of the host plant. But the data show that under such applications the nodule formation is more than trebled.

While certain compounds stimulate nodule formation, others just as effectively reduce it. In this class fall the nitrates, the ammonia-containing or -producing compounds, and the sulfates. These data suggest, therefore, that infection and subsequent nodule formation are inseparably combined with the protoplasmic activity. Whether this activity is manifest by the organism or by the host plant, or by both, has not been determined. Certain facts, however, have been established. In those cases in which the substances applied inhibited nodule formation, the organism remained alive and was capable of producing nodules immediately on being brought under favorable conditions. Further, if the action of these inhibiting substances resulted in a modification of the morphological or the physiological activities of the plant roots, the effect appeared locally and did not extend to other parts of the plant than those actually in contact with the inhibiting agent. Whether the reverse would be true of stimulative substances was not determined, but indications are in the affirmative. These results are significant from the standpoint of immunity; for if these substances render the plant immune to infection by *B. radicicola*, then this immunity also is only local and does not extend to other parts of the plant than those actually in contact with the immunizing substance; in other words, the plant does not absorb enough of this immunizing material and transfer it to all parts of the plant so that it can be used thruout as a means of protection.

The effect that such substances may have on the existence of the legume organism in the soil has been pointed out by Wohltmann (1902), who suggests that the addition of certain substances may in time destroy all the legume bacteria and that fertilizers should be chosen to avoid this condition. This may be important in certain cases, as Wohltmann has shown; but in other cases it may not be so important, for if two substances are added to the soil, one that promotes and one that inhibits nodule formation, their effect may be to neutralize each other.

It has been observed occasionally, also, that when the pure culture used in this work was used by farmers, negative results were obtained. Certain parts of these data may be cited to explain the failure, especially those obtained with lime in its various forms, for under its action the nodule production was more than trebled. The soil condition itself, by the application of fertilizing substances such as ammonium sulfate, potassium or sodium nitrate, or potassium or sodium sulfate, may have changed so that nodule formation could not occur. The data should be of especial significance to those southern States where high fertilizer applications are customary.

SUMMARY

The chief points emphasized by this investigation are the following:

The causal organism of nodule production on soybean (*Soja max* Piper) is *Bacillus radicicola*. Its flagella are peritrichous, four being the largest number found. Its group number (which is a numerical system of recording the salient characters of an organism, and which was computed according to the card of the Society of American Bacteriologists for 1907) is B.222.3332033.

Of fifteen legumes grown in virgin Volusia silt loam soil, only one, *Trifolium pratense*, developed nodules without artificial inoculation.

The normal variation in nodule production under uniform conditions is probably not greater than ±12 per 100 plants, with an average of 3.59 per plant.

Of eighteen different nitrates added to Volusia silt loam soil in quantities appreciably below the amount necessary to cause injury to the plants, sixteen either reduced or completely inhibited nodule formation.

Twenty-two chlorides were tested in Volusia silt loam soil as to their effect on nodule production. The results were stimulative in all cases but five, in three of which the application was toxic, and in one the result was within the normal variation. Ammonium chloride, in the amount used, appreciably reduced nodule formation.

Some sulfates, such as sodium, magnesium, calcium, barium, zinc, and others, depressed nodule formation when applied to Volusia silt loam soil.

Phosphates in soil cultures increased nodule production. Their action was not so pronounced, however, as that of the chlorides.

Ammonia-containing or -producing compounds in most cases either reduced or entirely inhibited nodule production. When the ammonia was combined with a stimulating radical, its action was somewhat neutral.

Calcium compounds added to Volusia silt loam soil were in most cases effective in stimulating nodule formation. Calcium sulfate and calcium nitrate, however, reduced the number of nodules formed.

The carbonate radical showed no appreciable effect on nodule production.

Carbon-containing compounds, such as sugars, oxalic, lactic, and citric acids, tartrates, caffein, and cumarin, stimulated nodule production when in soil culture.

Moisture has an effect on nodule formation. As the moisture was increased from 25 per cent of the dry soil to 75 per cent, the nodule formation was correspondingly increased.

In distilled water cultures nodules were not produced except in rare cases, even tho various nutrient salts, in concentrations such as are used in Pfeffer's solution, were present singly or in combination. In distilled water which had been shaken with carbon black, nodule formation occurred only in rare cases. However, when the distilled water was shaken with carbon black and various salts in certain molecular concentrations were added to it, nodules appeared in appreciable numbers. This was especially true of the nitrates, the chlorides, and potassium and sodium sulfate.

Nitrates or sulfates applied to soil in quantities sufficient to inhibit nodule formation did not destroy *Bacillus radicicola* nor reduce its ability to produce nodules when brought under favorable conditions. Similar results were obtained with distilled water cultures alone and with cultures in distilled water to which were added nutrient salts singly or in combination.

The composition of the soil solution is a factor in controlling nodule production.

The time required for the legume organism to penetrate the tissue of the host plant is about five hours.

The inhibiting action of nitrogenous compounds on nodule formation is local in character.

ACKNOWLEDGMENT

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The bibliography appended is intended to cover most of the articles that deal incidentally or purposely with factors influencing nodule production; also, to lead readers to literature where descriptions of and opinions regarding *Bacillus radicicola* may be found. Many of these references have been an aid and an inspiration to the writer in directing the investigation.

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STUDIES ON CLUBROOT OF CRUCIFEROUS PLANTS

CHARLES CHUPP

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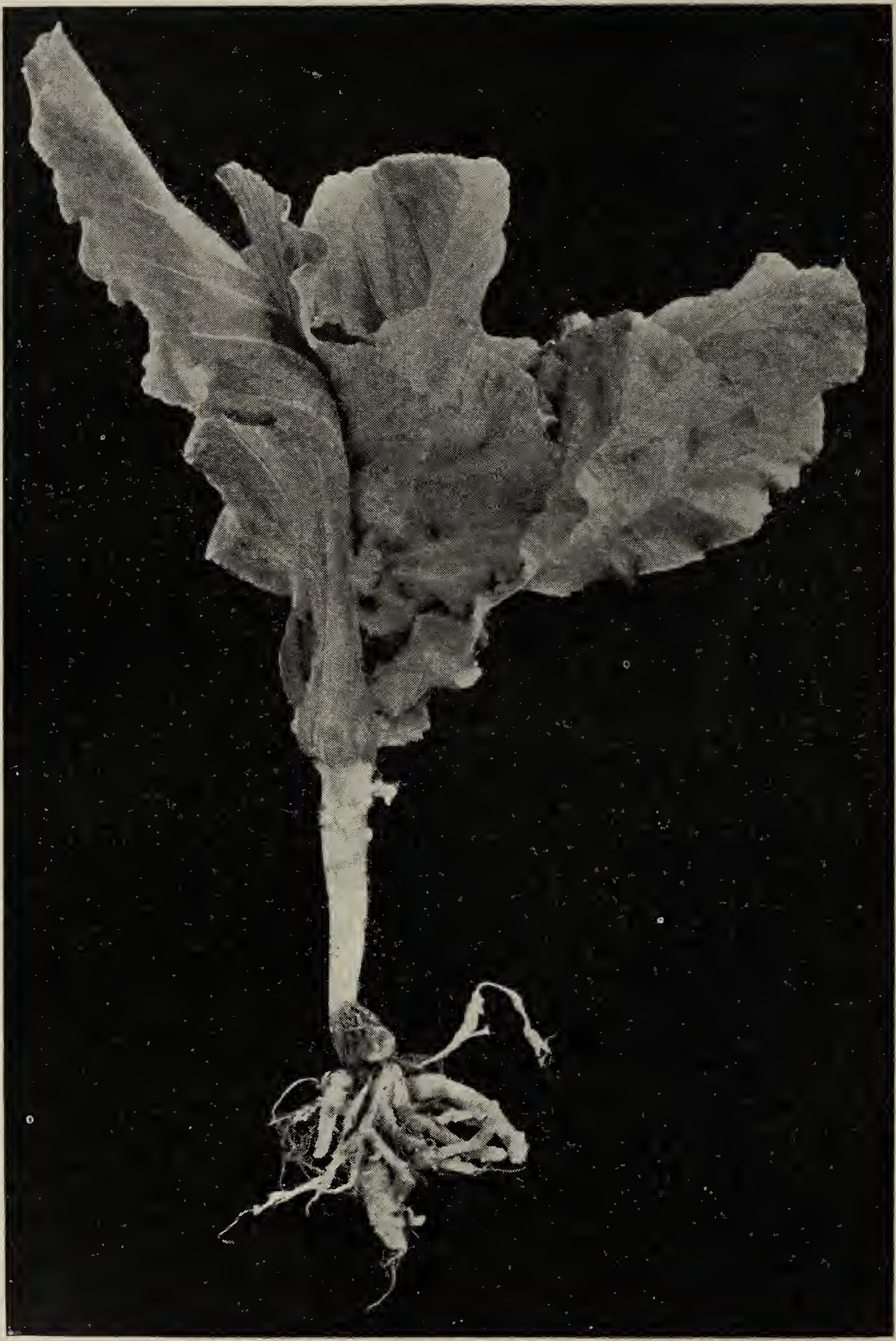

FIG. 95. DISEASED CABBAGE PLANT SHOWING THE THIN STALK AND THE ABSENCE OF A HEAD

STUDIES ON CLUBROOT OF CRUCIFEROUS PLANTS[1]

CHARLES CHUPP

Such an extensive literature on clubroot of cruciferous plants has accumulated that it would seem impossible for any one point to have escaped careful consideration. But when a close examination is made of all the data, it soon becomes apparent that only such prominent phases as symptoms, cytology of the organism, and control methods, have been dealt with extensively, while certain other less conspicuous features have been neglected. There still remain to be satisfactorily solved the following problems: (a) the part played by swarm-spores in the dissemination of *Plasmodiophora Brassicae* Wor., the organism that causes clubroot; (b) spore germination; (c) the manner in which the pathogene enters the host; (d) the distribution of the organism thruout the tissues of the root; (e) formation and size of the spores; and (f) the relation of bacteria to the normal development of the myxomycete. It is for the solution of these problems that the following investigations have been conducted.

DISSEMINATION

In a general way the manner in which the spores are carried is known, altho two errors are often met with in popular descriptions. For example, in a number of reports (Atkinson, 1889, Carruthers, 1893, and others)[2] are statements implying that swarm-spores swim about in the water of the soil until they reach a cabbage root. In a way this is correct, but the average layman at once pictures the swarm-spores as traveling from row to row of plants or even from field to field. Nothing could be more erroneous, for, as far as dissemination is concerned, the motility of the swarm-spore plays such a slight part that it need not be considered. Its energy is not directed in a straight line, and the very minuteness of the organism would preclude any effective locomotion in the time that it remains alive.

In order to test the distance to which swarm-spores may travel in the soil, a box two feet square was filled with clay mixed with muck soil, and diseased roots were buried in one end. Cabbage seeds were then sown in the box, care being taken not to transfer any of the soil from the place where the inoculum was inserted. When the seedlings over the area

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[1] Also presented to the Faculty of the Graduate School of Cornell University, September, 1916, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

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[2] Dates in parenthesis refer to bibliography, page 451.

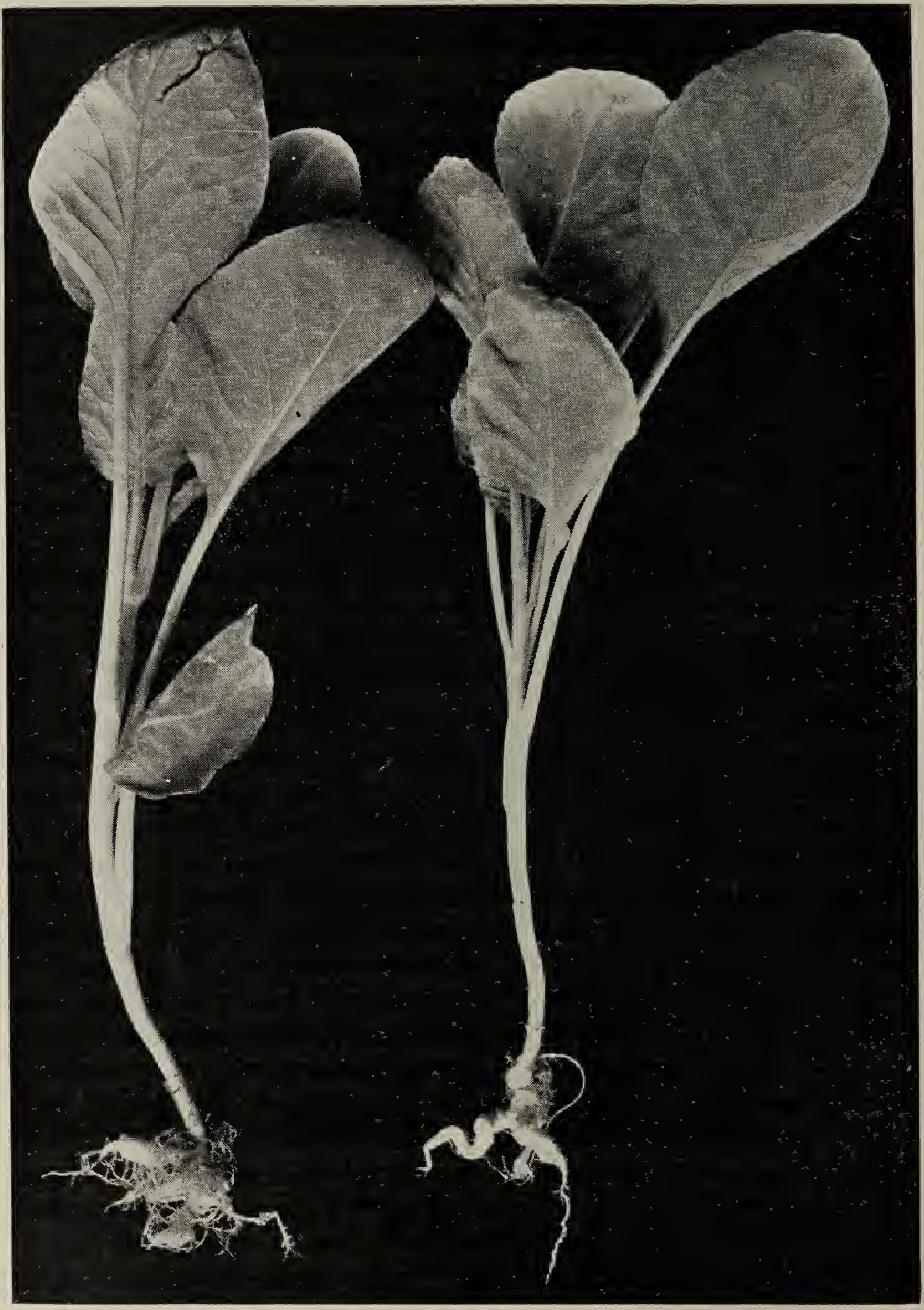

FIG. 96. DISEASED CABBAGE SEEDLINGS

where diseased roots were buried had become so badly infected that they began to wilt and turn yellow, all the plants were discarded and the plat was reseeded. Different crops of seedlings were thus grown for almost a year, and, altho there was a gradual spread of the organism, it was only by careless watering and planting that the pathogene was carried in the soil to all parts of the box.

Cabbage seeds were sown in a greenhouse plat in rows ten inches apart, the bottom of each trench being first lined with infested soil. Halfway between these rows were sown other rows, in the trenches of which no infested soil was placed. The inoculated plants (fig. 96) became infected at a very early stage, while the plants that were only five inches away from the spores remained healthy until they were almost mature.

A few authors (Carruthers, 1893, and others) claim that wind is an important agent in spore dissemination. This may be true in light, loose soil, and in localities where strong winds prevail, but in none of the observations made by the writer was there a single case in which the presence of the organism could be explained on this basis. On the other hand, many of the fields showed that if the soil were not transferred by some agent other than the wind the pathogene did not spread. On Long Island, New York, a certain field was observed, one corner of which was slightly lower than the adjoining part. This corner had been used for a garden until clubroot became so prevalent that the plat was no longer profitable for the raising of crucifers. It was then tilled with the remainder of the field for three years while various crops were grown, cabbages not being planted again until the fourth year. A space only slightly larger than the original garden then displayed the presence of clubroot. If wind had been an important agent it would have had an opportunity here, for the land was almost level and the soil was very loose. This was only one of several cases in which the same conditions were observed.

SPORE GERMINATION

Very few persons have been successful in germinating the spores of *Plasmodiophora Brassicae*, and of those few who have been so fortunate, still fewer have seen the actual process. Woronin (1878) gives a brief description and a series of illustrations which have been copied by nearly all later writers on this phase of the subject. The general experience, however, seems to have been like that of Maire and Tison (1911) while working with *Tetramyxa parasitica* Goebel. They saw only one spore actually germinating, and after a very long, tiresome vigil they left it for a few minutes. On returning from their temporary absence they found that the phenomenon had been completed. Notwithstanding these difficulties, Eycleshymer (1894) not only found swarm-spores, but also found that when left in the culture for a few days these apparently fused into larger bodies, thereby reacting in much the same manner as Kunkel (1915) found to be the case with *Spongospora subterranea* (Wollr.) Johnson. Kunkel discovered that each cell of a spore ball produces a single uninucleate amœba which soon fuses with others of its kind to form a small plasmodium. This occurs not only in the case of spores in the soil, but even with those still in the base of the old sorus.

There are several obstacles to be encountered in trying to observe the actual emergence of the protoplasmic mass from the old spore wall. First, it is difficult to get a very large percentage of germination unless the most favorable conditions are present. Secondly, all observations must be made with the oil-immersion objective. When the protoplasm is about halfway out, the spore wall and the emerging protoplast begin to move, making it hard to keep them in focus or even within the field. Consequently, when the process seems almost complete there is a sudden swift whirl, and the swarm-spore, with the adhering empty wall, darts out of sight. When located again, the spore wall is empty, and the swarm-spore, lost among others, is impossible of identification. For this reason no actual separation of the protoplasm from the spore wall has been seen, but enough of the process has been observed to enable investigators to determine the general method by which this is accomplished and to be sure that a spore gives rise to only one swarm-spore.

It was soon learned that spores do not germinate well, if at all, in distilled water, and further that, altho from one to five per cent of the spores taken directly from a fresh root germinate in muck-soil filtrate, a much larger percentage of germination can be obtained by exposing the roots to freezing temperatures for two weeks or longer. This was accomplished by tying the roots in cheesecloth and burying them under the snow, or in summer by keeping them in the refrigerator for that length of time. Drying the roots also seems to have a beneficial effect on germination, altho this must not be carried to the extreme. The muck-soil filtrate was made by filling an ordinary flowerpot with muck, placing it over a large funnel lined with filter paper, and then pouring hot water on the soil. The resulting medium was of an amber color and slightly acid.

Temperature conditions also influence germination of the spores. It was practically impossible to obtain infection in the greenhouse during the coldest winter months when the temperature was from 10° to 18° C. The spores also fail to germinate at ordinary room temperature (from 16° to 21° C.). The optimum temperature for germination proved to be from 27° to 30° C. This, however, is not the case when spores are placed in test tubes on agar with young cabbage seedlings, for under such conditions infection takes place at a temperature of from 16° to 21° C. The presence of the host seems in some manner to exert an influence which to a certain extent takes the place of that offered by a greater amount of heat.

Usually the first sign of germination is a swelling of the spore, which sometimes becomes a third larger. This occurs within a period of from fifteen minutes to eight hours after the spores are placed in the medium, altho the best time for examining the culture proved to be at the end of six hours. After the swelling of the spore there is a bulging at one side. The protoplasm withdraws from near the opposite wall and leaves a nearly hyaline semicircle about two-thirds of the distance from the center. The pressure exerted splits the wall just enough to permit the protoplasm to ooze out. Unlike Woronin (1878) and Mangin (1902), the writer has never observed the protoplasm taking the various shapes that these authors assign to it, but while oozing out it collects in a sphere or a hemisphere against the wall on the outside. When about half of the protoplasm has escaped, the whole body becomes motile. At first there is only a trembling, which gradually increases in violence until the spore is turned around entirely. The activity now becomes so great that it is with difficulty that the microscope is kept focused on it correctly. The final struggle is apparently a rapid spurt across the field, when the swarm-spore is liberated from its container and at once begins its rotatory activities. The whole process under the microscope consumes an hour or longer. Evidently the strong light turned on a spore retards the action, for in many cases the spores that had begun to germinate when placed in view showed no further signs of development, while those kept in the dark germinated much more rapidly and when examined at the end of the same period were found actively swimming about.

A considerable part of the contents is left within the old spore wall, so that when the broken part is turned upward it has the appearance of a circle bounded by a darker band, the width of which is about one-third of the radius. If, however, the open part is on the side, the residue within the spore wall resembles more nearly a crescent (fig. 97).

The swarm-spore when alive measures from 1.7 to 3.5 μ in length, being more or less pyriform with a thick flagellum at the smaller, or anterior, end and a vacuole near the posterior end. Unless stained, the flagellum cannot be seen under the microscope. The line of locomotion is never a straight one, for the flagellum is lashed about by the beak, which is constantly doubling backward so that a whirling motion is given to the swarm-spore. Altho the latter is a naked mass of protoplasm, the writer has never seen the various shapes which Woronin (1878, Pl. XXXIV) has pictured; it was observed in every case to be globose or pyriform, never having pseudopodia-like structures.

It has been difficult to properly fix swarm-spores for staining flagella. The first method of staining tried was that ordinarily employed for bacteria, namely, Loeffler's mordant and Ziehl's carbol fuchsin. When bacteria were in the mount their flagella were stained, but those of the swarm-spores had evidently disappeared. The process was then modified slightly, and the cover-glass mounts, instead of being left to dry in the incubator, were placed on slides in preparation dishes with ground-glass tops. In the bottom of each dish was placed a few cubic centimeters of osmic acid, and the lid was then carefully fitted in place. The acid killed a few of the swarm-spores before the flagella could be withdrawn, but never a very large proportion. Besides demonstrating the presence of flagella, the stained material also displayed different stages of germination (fig. 97).

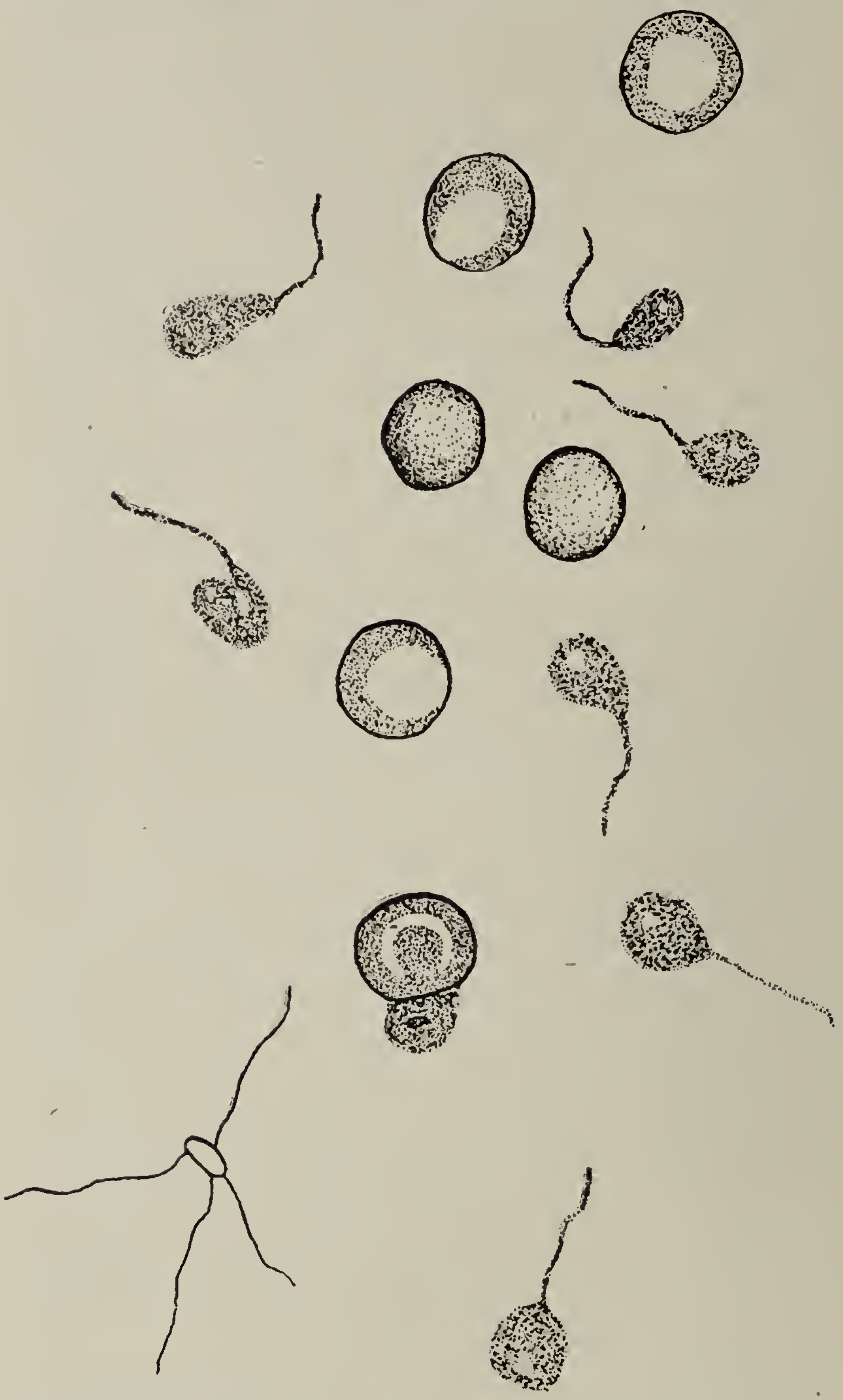

FIG. 97. SPORES AND SWARM-SPORES OF PLASMODIOPHORA BRASSICAE

The two spores at the top have already germinated. The germinating spore and the two swarm-spores near the bottom were drawn from stained mounts. The bacillus shown is the form found oftenest in older diseased roots. × 2100

Kunkel (1915) was able to get spore germination of *Spongospora subterranea* on an agar medium. *Plasmodiophora Brassicae* evidently does not react in the same way. During the three years of the present work, repeated efforts were made to secure not only germination on the surface of agar, but also formation of plasmodia. Unless the spores were immersed in water there was no development. They lay there until the agar became so dry that they finally lost their viability. If enough of the muck-soil filtrate was added, the swarm-spores appeared but there was no further development. They were active for a certain time, and then encysted and remained in that condition as long as the cultures were kept. This experiment was performed on four kinds of agar media, on potato plugs, and on healthy cabbage roots. In no case were there any signs of further growth. This, with subsequent infection experiments, indicates very strongly, if it does not prove positively, that the swarm-spores never fuse. This is in keeping with what has been found, or at least suggested, in all other cases of parasitic slime molds, *Spongospora subterranea* excepted.

If spores for germination are taken from roots that have not previously been disinfected, there are often found in the cultures flagellate bodies which are almost small enough to resemble swarmspores. They are larger, however, are more active, and when stained are more or less reniform, having two flagella arising from the concave side (fig. 98). These, as pointed out later, belong to another organism.

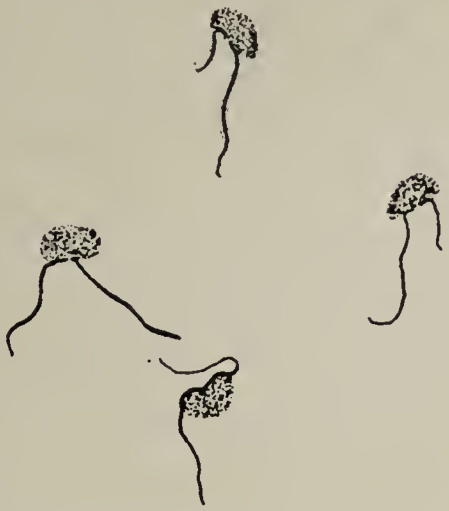

Fig. 98. FLAGELLATE ORGANISMS ASSOCIATED WITH PLASMODIOPHORA BRASSICAE

PENETRATION

In the knowledge of the life history of *Plasmodiophora Brassicae*, there has always been a gap between the swarm-spore stage and the amœba within the cell, the true sequence of development never having been shown. Most writers pass over the difficulty with the mere statement that the organism enters the root and there begins its parasitic life. Woronin (1878), in this as in nearly all other points connected with clubroot, is the only one who has tried to fill in the gap. In a way he succeeded, but, as his plants died before reaching the stage in which invasion of any of the tissue took place, he is not sure that the root hair is the real point of entrance. He placed cabbage seedlings in shallow watch glasses, in water well supplied with spores. For some reason the plants began dying before hypertrophy took place. When the roots were examined microscopically, the root hairs were filled with amœbæ but nothing further had happened. The question still remained, whether these infections under normal conditions would have been followed later by invasion of the cortical cells, or whether the case was similar to that which Schwartz (1914) found in species of Ligniera. Schwartz thinks that penetration takes place near the apex of the root, so that when the root hairs act as bearers of the amœbæ the parasite does not advance farther than the base of the cell.

Most writers believe not only that the apical cells and the root hairs act as infection courts, but also that the epidermal cells can be infected directly up to the time when the epidermal layer is thrown off (Woronin, 1878). Somerville (1895) gives an observation as proof of this statement. He often found swellings high up on the roots of turnips, where he declares no root hairs could have been responsible for the entrance of the slime mold, which must have penetrated the thick cuticle. This question of entrance has a direct economic bearing on control, for, if Somerville's statement is true, Massee's (1903) assumption is certainly erroneous. Massee states that the Cruciferæ can be attacked only during seedling time, and that after six weeks they are practically immune. It is doubtful whether either Somerville or Massee interprets the conditions correctly. If infection could not take place after six weeks, the grower could control the disease merely by late transplanting and the proper care of his seed beds; but this has evidently not proved to be the case in practice.

Maire and Tison (1909, 1911) and Schwartz (1910, 1911, 1914) have done nearly all the work that has been reported on the parasitic slime molds other than *Spongospora subterranea* and *Plasmodiophora Brassicae*. It is interesting to note that their conclusions agree very closely, and that they feel sure the amœbæ enter oftener thru the apical cells than otherwise, altho the root hairs also may serve as points of entrance. They made no particular study of this question, but were led to this conclusion by finding uninucleate amœbæ in the cells near the growing tips. Their opinion is substantiated also by the presence of rows of diseased cortical cells, the divisions of which apparently take place when still very near the initial cells in the root tips. The powdery scab pathogene, *Spongospora subterranea*, passes directly thru and between the epidermal cells into the tuber (Kunkel, 1915).

There is more or less difficulty in studying the nature of penetration in the case of *Plasmodiophora Brassicae*, because of the fact that the uninucleate amœbæ are so small. They can be recognized only under a very high magnification, and, since they are so nearly transparent, stained sections must be used for all the work. A very large number of both longitudinal and cross sections were prepared, the thickness ranging from three to fifteen microns, and the staining was done with the combination stains of safranin, gentian violet, and orange G. These proved best for differentiating the parasite from the host, especially when orange G was used in excess.

There is no possible stage in penetration that was not represented in the preparations. Large, as well as very small, roots were sectioned, and a great number of epidermal cells showed amœbæ. But in a careful study of almost three hundred slides, none of these cells showed that penetration had taken place directly thru the cutinized wall. In a number of cases this appeared to be true when the sections were first examined, but a more detailed study of the same series showed the invaded cell to be in every case the basal portion of a root hair. This, together with the fact that no new swellings are ever found at any great distance from the region where root hairs might have existed previously, has led the writer to believe that seldom, if ever, is there direct penetration into simple epidermal cells.

This holds true not only for the area above the place where the root hairs have disappeared, but evidently also for the space near the extreme tips where the hairs have not yet been formed. Not only did these slides demonstrate this point, but infection secured under aseptic conditions in test tubes has confirmed it. The small root-tips were so placed that they were the first to come into contact with particles of diseased tissue and the muck-soil filtrate containing free spores. When these rootlets were sectioned and stained, they showed various stages of root-hair invasion, but no amœbæ were found in any of the apical cells. The evidence presented in these slides shows that these invasions are not, like those which Schwartz (1914) suggested for *Ligniera* sp., confined alone to the epidermal cells of which the hairs are outgrowths. The passage of amœbæ from the epidermal cells into the cortical tissue is demonstrated not only by the position of the amœbæ within the parenchyma cells, but also by actual cell-wall penetration.

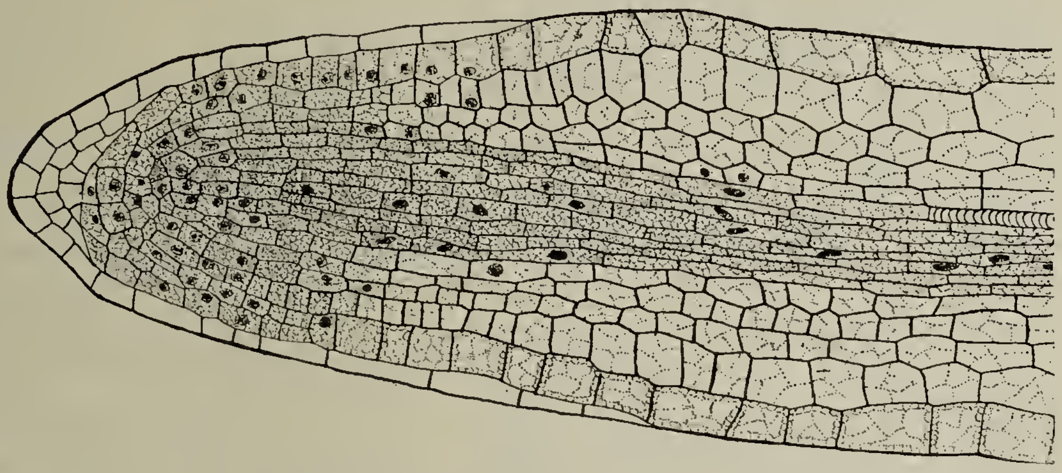

Fig. 99. LONGITUDINAL SECTION OF A CABBAGE ROOT

This shows the tip of the cabbage root protected by the cells of the root-cap. × 110

The argument advanced for other species of Plasmodiophoraceæ, that infection must take place in the growing tip where cells are dividing rapidly because the organism often occurs in definite rows of the cortical cells, does not necessarily apply to *Plasmodiophora Brassicae*. A glance at a section of a root tip (fig. 99) indicates the difficulty that a swarm-spore would encounter in entering at this point. The rootcap does not merely protect the root tip, but a row of its cells extends upward almost halfway to the root hairs. The remaining distance is protected by a comparatively heavy cuticle, leaving the root hair as practically the only vulnerable point. Moreover, the presence of the organism in continuous rows of cells can be explained in another manner. The condition shown in figure 100, B, gives no indication as to where penetration occurred. Yet by moving the section the length of half a dozen cells, there is seen an uninterrupted connection of diseased tissue between this particular row and the epidermis (fig. 100, A).

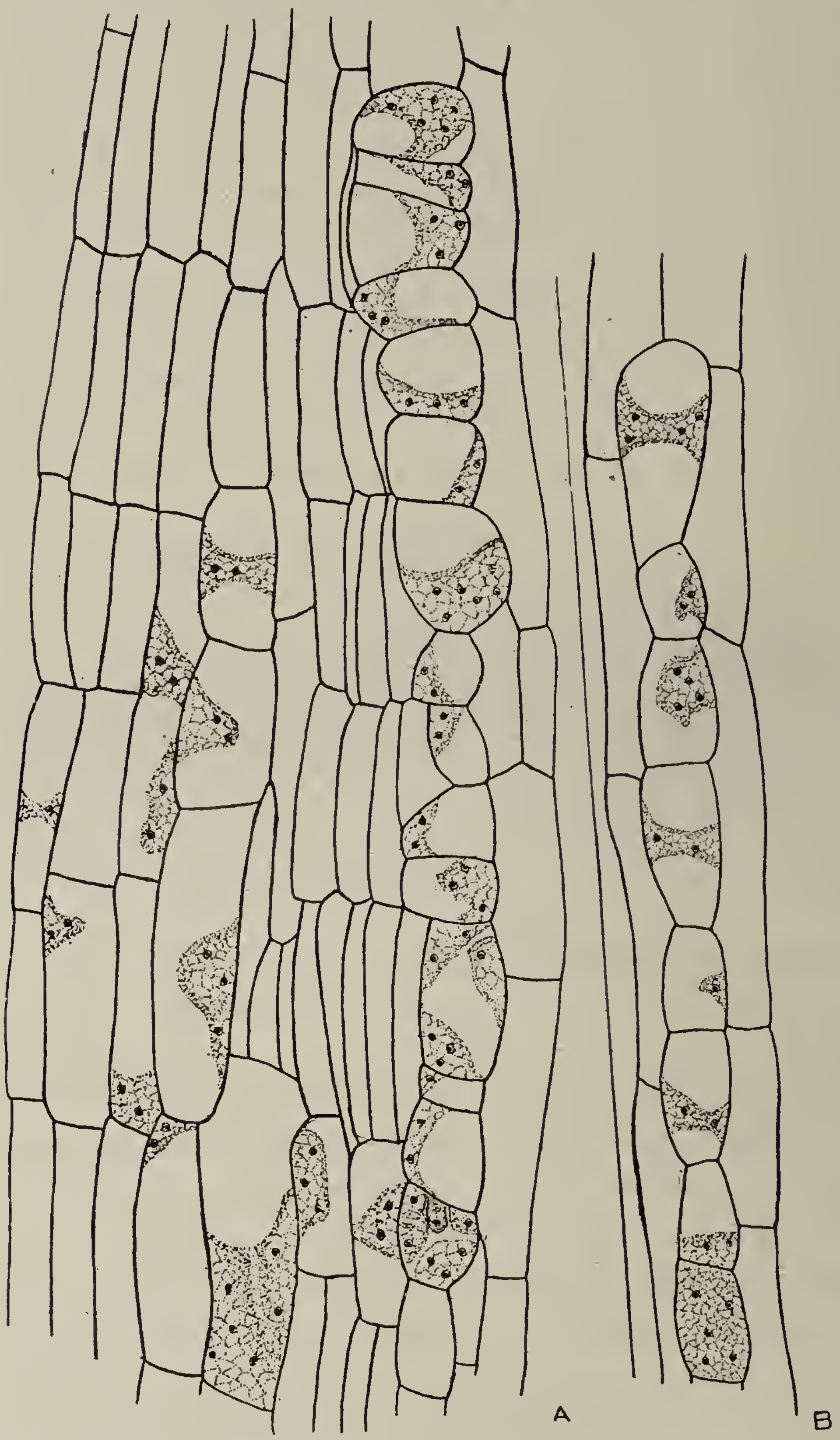

FIG. 100. DISEASED CORTICAL TISSUE OF A CABBAGE ROOT

A, A row of diseased cortical cells; B, another row of diseased cortical cells connected with the epidermis by an unbroken line of diseased tissue. × 110

So far as the writer's observations go, there seems to be no question but that penetration does take place thru the root hairs, and thru these only. Eycleshymer (1894) suggests that wounds caused by insects may provide a means of entrance for the parasite. This is altogether probable; yet the writer has never observed any indications of this condition, so that if it ever happens it apparently does so very rarely. If cultures could be secured within pieces of healthy disinfected roots in test tubes, it would at least be evidence that such wound infection might take place. Pinoy (1905) removed small pieces of healthy roots by means of sterilized pipettes, and by inoculating them with spores secured cultures of the organism, provided the tubes were sealed so that the aërobic bacteria were deprived of oxygen. His discussion of this point is somewhat lacking in clearness. Besides, the time in which he claims spores were produced in the roots is unusually short. He gives it as five days, which is the same time that under the most favorable circumstances it takes swarm-spores to pass thru the root hairs into the cortical tissue and to develop sufficient hypertrophy to be visible to the naked eye. Kleimenov (1912) tried the same experiment and failed. In the writer's experiments it was also tried repeatedly, always with failure. If the cultures were kept free from bacteria the root underwent no change. If bacteria were added, the root became soft and foul-smelling, whether the test tubes were closed with cotton plugs or sealed with paraffin over cork or cotton stoppers. Sealing did not stop the growth of the bacteria, as Pinoy claims for his experiments.

Altho authors popularly describe with some assurance various ways in which the organism may enter the host, no one has observed the real process. Even Woronin, who believed that the organism passes thru the root hair, was never able to demonstrate this clearly. Nevertheless he felt assured that it enters in the form of a uninucleate amœba, and his opinion has been accepted by most investigators. A few workers, such as Worthington G. Smith (1884), maintain that the organism enters the root in the form of a plasmodium, but this theory has never been accepted generally. The question was revived again when Kunkel (1915) studied the powdery scab of potato, in which the swarm-spores are found to fuse before attacking the host.

There seems to be no doubt in the minds of Maire and Tison (1911) and Schwartz (1914) that all the other known parasitic myxomycetes enter immediately after the swarm-spore stage. This conclusion is based on the fact that many of the slides of these investigators show the uninucleate forms in the apical cells. There is no other theory that would explain this phenomenon, unless a single uninucleate amœba of an infecting plasmodium passes thru the intervening cell walls and spreads in this manner thru the tissue. This is improbable.

Because of the diminutive size of the swarm-spore, the only satisfactory method for studying penetration appears to be by means of stained sections of roots showing the earliest stages possible. In the first part of this work, young plants from the greenhouse were used, but none of the stages were young enough to give just what was desired. An attempt was then made to grow plants in large test tubes on screens so arranged that the roots were hanging in muck-soil filtrate containing a heavy suspension of spores. The roots did not develop well when immersed in the liquid medium, and but few root hairs were present. An attempt was then made to grow seedlings in soil, in flats six inches square, with diseased tissue so plentiful that none of the plants could escape infection. The roots were fixed and embedded at intervals before the time when ordinary symptoms became apparent to the naked eye. This gave nearly all the early stages of infection, but the adhering particles of soil, which could not be washed off without sacrificing the hairs, not only were detrimental to the microtome knife, but also obstructed a clear view of the cell walls. Finally a method was devised whereby infected roots could be procured free from any other contamination. Diseased roots that contained spores but were not far enough advanced to be invaded by bacteria were sterilized on the surface with mercuric chloride and transferred to agar slants in test tubes. After two weeks cooling in the ice chest they were finely minced in the agar, and incubated until it was clear that no bacteria were present in the tissue, from which they might have been liberated by the cutting. After enough time had elapsed to insure perfect freedom from any saprophytes, a few drops of sterilized muck-soil filtrate, and a young cabbage seedling which had been grown from disinfected seed on agar in a petri dish, were added. It was necessary to exercise care in adding sufficient liquid to permit spore germination and not have an excess, which would injure the root. A few drops would not evaporate until all the swarmspores had ample time to be set free and attack the root hair. The process was somewhat long, and very often roots were chosen which were too old and were already contaminated with bacteria. In spite of all the difficulties, enough pure cultures were obtained to provide a large number of sections which showed all sizes of amœbæ.

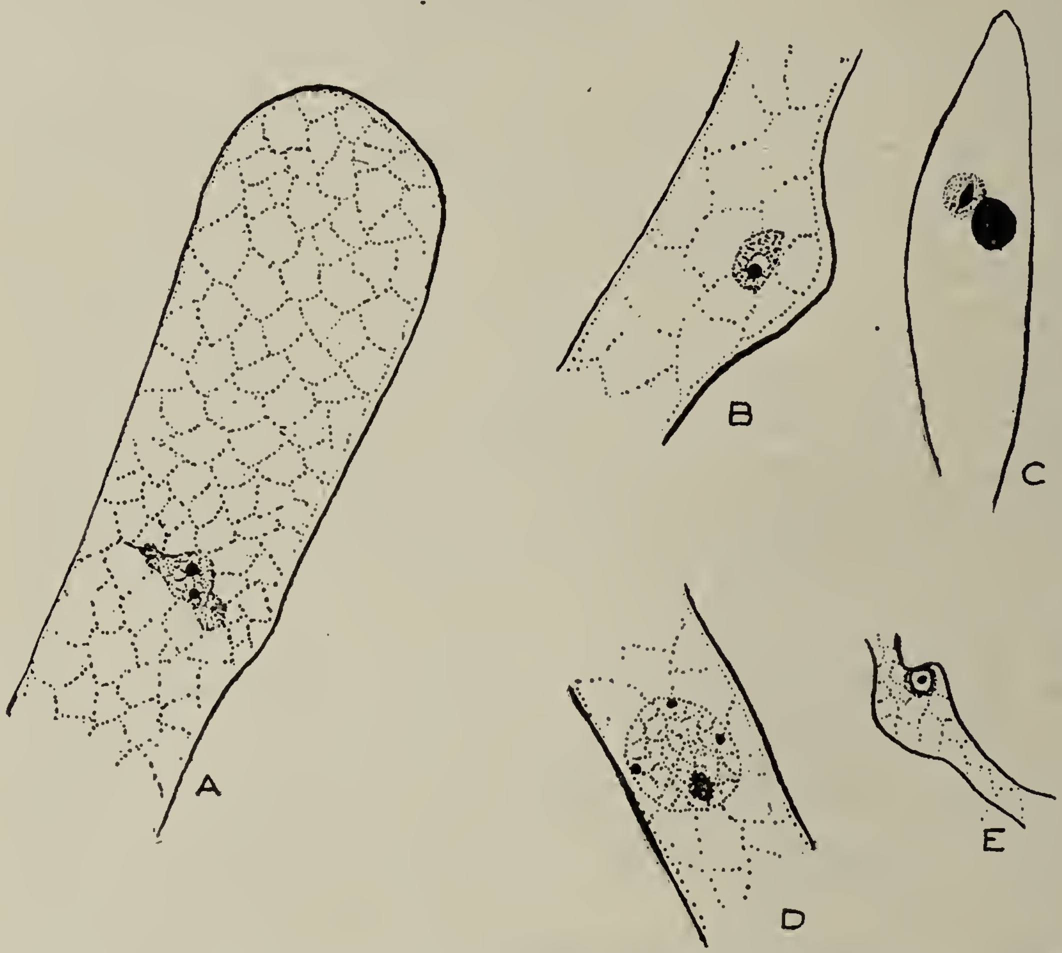

FIG. 101. THE AMŒBA OF PLASMODIOPHORA BRASSICAE IN A ROOT HAIR

A, A root hair with an amœba showing two nuclei. B, A uninucleate amœba in a root hair which shows an abnormal swelling in the immediate vicinity of the organism. C, A uninucleate amœba in a tangential section of a root hair; the nucleolus has elongated, as it ordinarily does just before nuclear division. D, A host nucleus in a root hair, showing its size as compared with that of a uninucleate amœba. E, A uninucleate amœba in a shrunken, distorted root hair. × 1600

The first and most important thing shown by the stained sections was that *Plasmodiophora Brassicae* enters the root hair as a uninucleate amœba, not as a plasmodium. There are several facts that prove this conclusively, even tho the actual phase of the organism passing thru the wall was never observed with certainty. A number of slides show cases that might be interpreted as actual penetration, but as the nucleus in no case appears in the act of making the passage one cannot be certain of such an interpretation. Nevertheless, numerous cases are to be found of a uninucleate amœba just within the wall of the root hair and far enough away from any other infection to preclude all possibility of its having reached there except by entering singly thru the wall (fig. 101).

Evidently the reason why no one has recorded this stage heretofore is because the amœba hardly enters before nuclear division and growth takes place. Some slides show binucleate amœbæ still within the hollow of the enlarged cavity, apparently produced by the stimulus of the parasite. Other sections show trinucleate amœbæ, and it is not difficult to find amœbæ with six or more nuclei (fig. 104, page 436).

This series of stages would indicate that penetration takes place in the uninucleate stage, particularly since the large multinucleate amœbæ are to be found, in nearly every instance, near the base of the root hair, while the smaller and fewer-nucleate amœbæ are always on the inside of the root-hair wall about two-thirds of the distance from the base. Amœbæ are seldom found in the tip of the hair.

Another point that confirms the above view of penetration is that in the absence of growing host roots the swarm-spores develop no further when the spores are germinated under artificial conditions, and after a short period of activity the swarm-spores encyst and eventually die. If plasmodia are formed under normal conditions, there should have been at least a suggestion of this in a few of the numerous cultures used in the experiments.

In this connection also the very interesting question of sexual fusion arises. It is believed by several cytologists that there are two nuclear divisions just before spore formation and that one of these is probably a reduction division. If this is true, it would imply that somewhere in the life cycle there has been a fusion. Winge (1913) and others believe that this occurs among the swarm-spores before they enter the host. Prowazek (1905) is of the opinion that the amœbæ within the host unite and then the nuclei fuse. Even Nawaschin (1899) believes this union takes place, but apparently he thinks it is of no significance in reproduction. Maire and Tison (1909, 1911) have disproved the amœbal union, and their view is certainly correct, for it is possible to find slides showing one amœba breaking up into spores while in another, immediately adjoining, division has not yet begun (fig. 102, D). On the other hand, it would seem that the fusion of two swarm-spores would give an increase in size, but the measurements of amœbæ just after penetration show them to be no larger than the swarm-spores just out of the spore wall. Consequently Winge's theory must be discarded. It thus appears that the real fusion stage, if there is one, is still to be discovered.

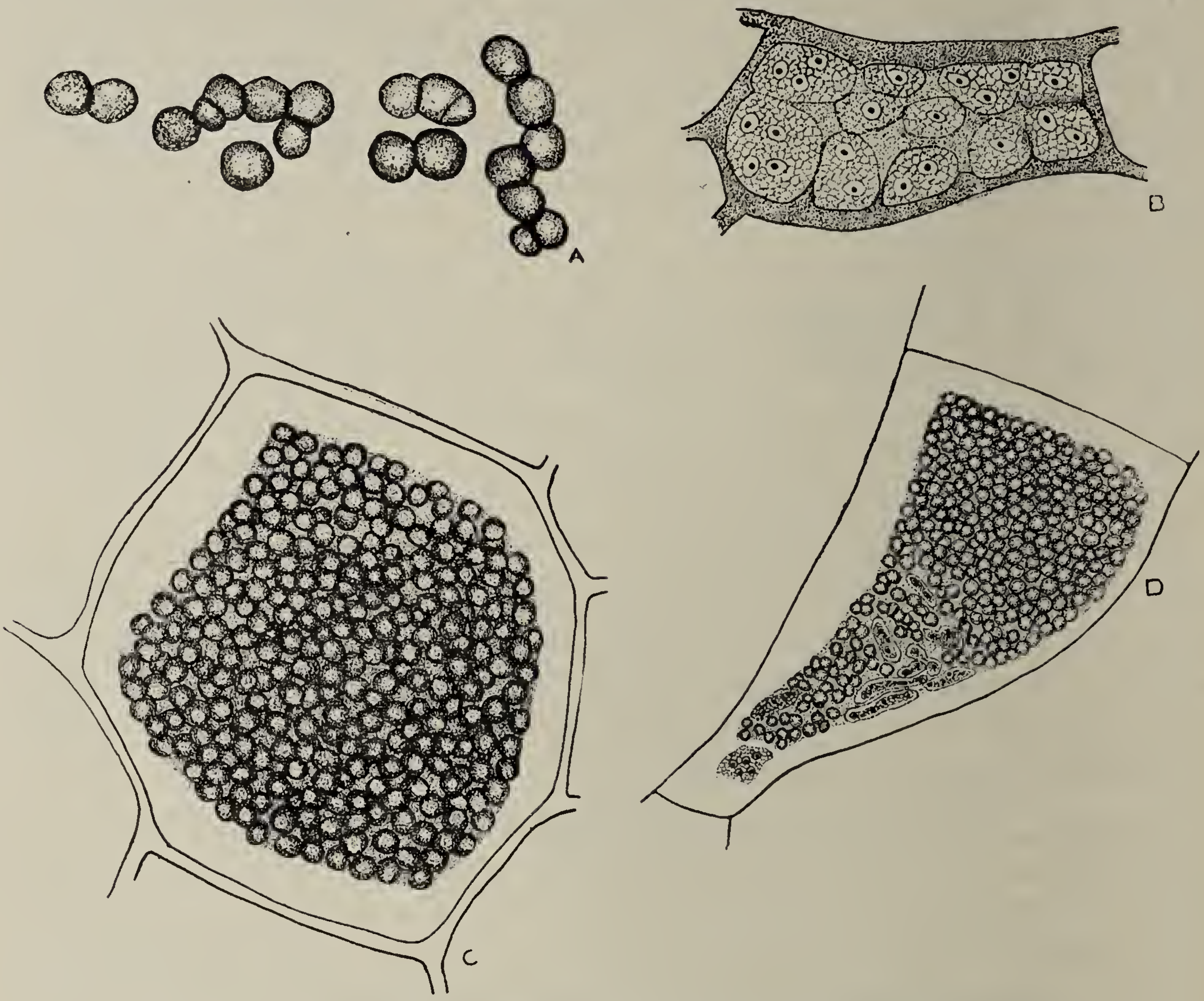

FIG. 102. SPORES AND AMŒBÆ OF PLASMODIOPHORA BRASSICAE

A, Spores before their final separation from one another; B, cell filled with amœbæ; C, cell filled with spores. All × 800. D, Formation of spores, × 500

DISTRIBUTION WITHIN THE HOST TISSUES

As stated above, the uninucleate amœba, just after its entrance into the host, lies at first in a small cavity produced by the outward swelling of the part of the root hair at the point where the organism entered. This protuberance is no doubt caused by the irritating presence of the parasite (fig. 101, A, B, E). Following penetration the amœba increases in size and pushes toward the center of the hair. The movement is accomplished by an actual amœboid creeping, and an elongation and gradual segmentation of the forward part. Woronin (1878) was able to observe the former method of locomotion in the living cells, and mentions it as the means by which the organism moves. Schwartz (1910), on the other hand, observed the growing of the amœboid tip in *Ligniera Junci* (Sch.) M. et T., and explains the change of position on that basis alone. A root hair is shown in figure 104, D, which apparently was infected near the tip, and as the organism grew rootward fission took place, so that when the anterior part of the amœba eventually reached the base of the cell the root hair was filled completely with the meronts, as Maire and Tison (1911) designate the segmented parts (fig. 103). This does not always take place, for there were many more cases observed in which the intact amœba reached the base of the cell (fig. 104, E, F). In either case, if the time consumed is too long, or if for any other reason sporulation begins, the amœba loses its power of further penetration into the cortical tissues. If, however, it reaches the inner wall of the root-hair cell, its pseudopodia are extended into the very smallest thread-like processes, which pass thru and into the cortical cell (fig. 105, E, F, G). Schwartz (1910), in describing penetration by *Ligniera Junci*, gives the same route of invasion but does not state how the passage from the epidermis into the cortical cells takes place. This question is of especial interest, since in the latter part of his discussion Schwartz states his belief that amœbæ never have the power of penetrating cell walls. There is no other apparent means by which this could be accomplished, for the epidermal cells seldom divide periclinally.

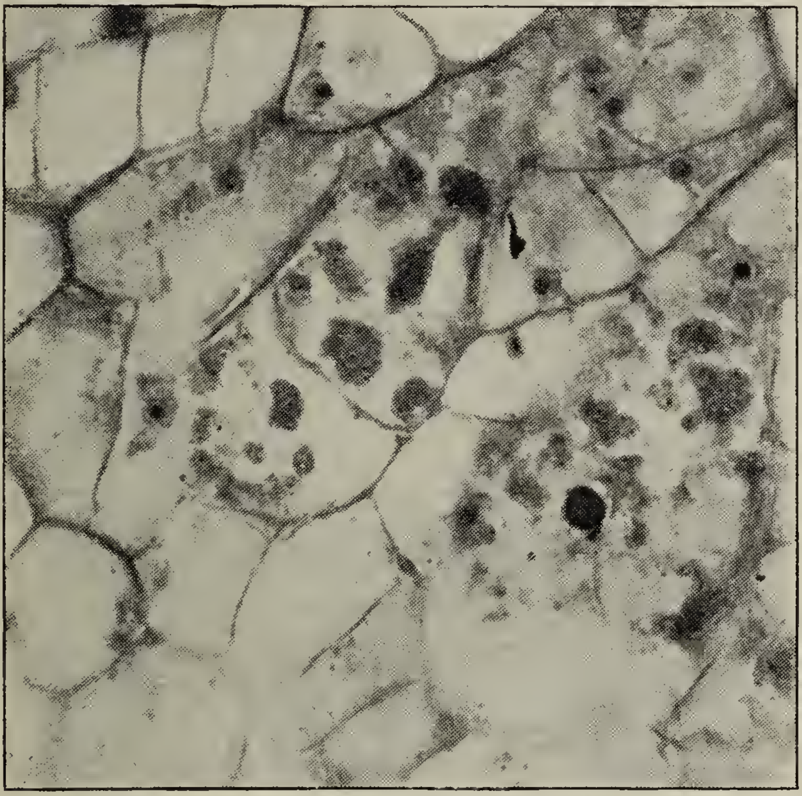

Fig. 103. PHOTOMICROGRAPH OF CELLS CONTAINING AMŒBÆ

One amœba has elongated considerably and is separating into meronts

It would be difficult to explain the wide distribution of the parasite within the root if cell-wall penetration did not occur, even tho it were taken for granted that invasion begins in the apical cells. The rootcap so fully protects these rapidly dividing primary cells that one must presuppose that in order to reach them the organism can pierce the walls. Then, in the maturer roots constant secondary thickening by the cambium takes place, which would ultimately push most of the diseased cells toward the periphery or isolate them near the center. This, however, does

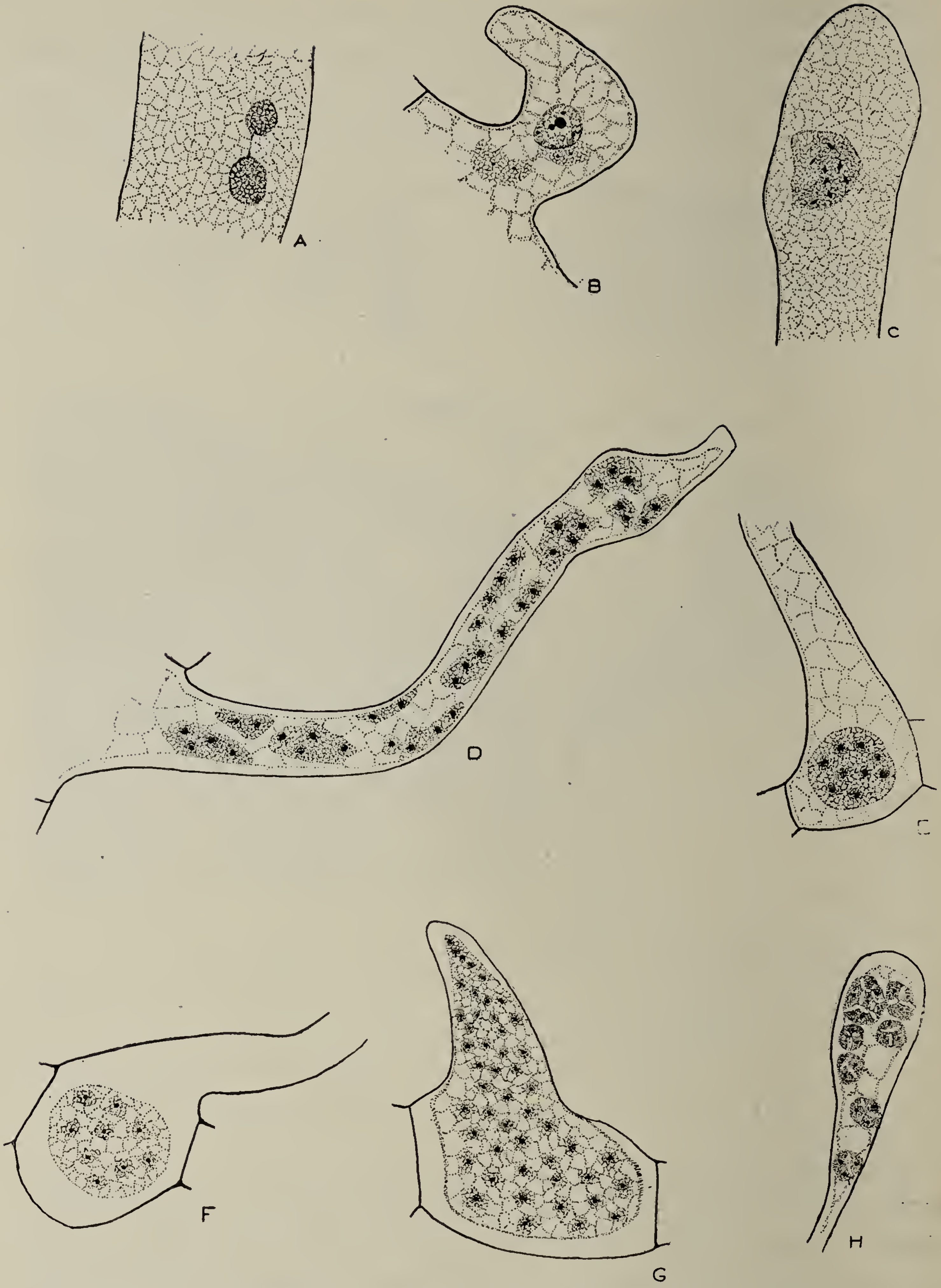

FIG. 104. SECTIONS OF CABBAGE ROOT HAIRS SHOWING AMŒBÆ

A, An amœba dividing by fission in a root hair. B, A much distorted and swollen root hair, with a small amœba partly surrounding its nucleus, which is also much enlarged. C, An amœba near the tip of a root hair; the nucleoli are elongated, as they ordinarily are just before nuclear division. D, A root hair filled with meronts. E and F, Amœbæ in epidermal cells of the root and at the base of root hairs; amœbæ about to break up into spores. G, A root hair filled with an amœba. H, A root hair filled with amœbæ breaking up into spores; the vacuolar channels between each nucleus are plainly visible. × 600

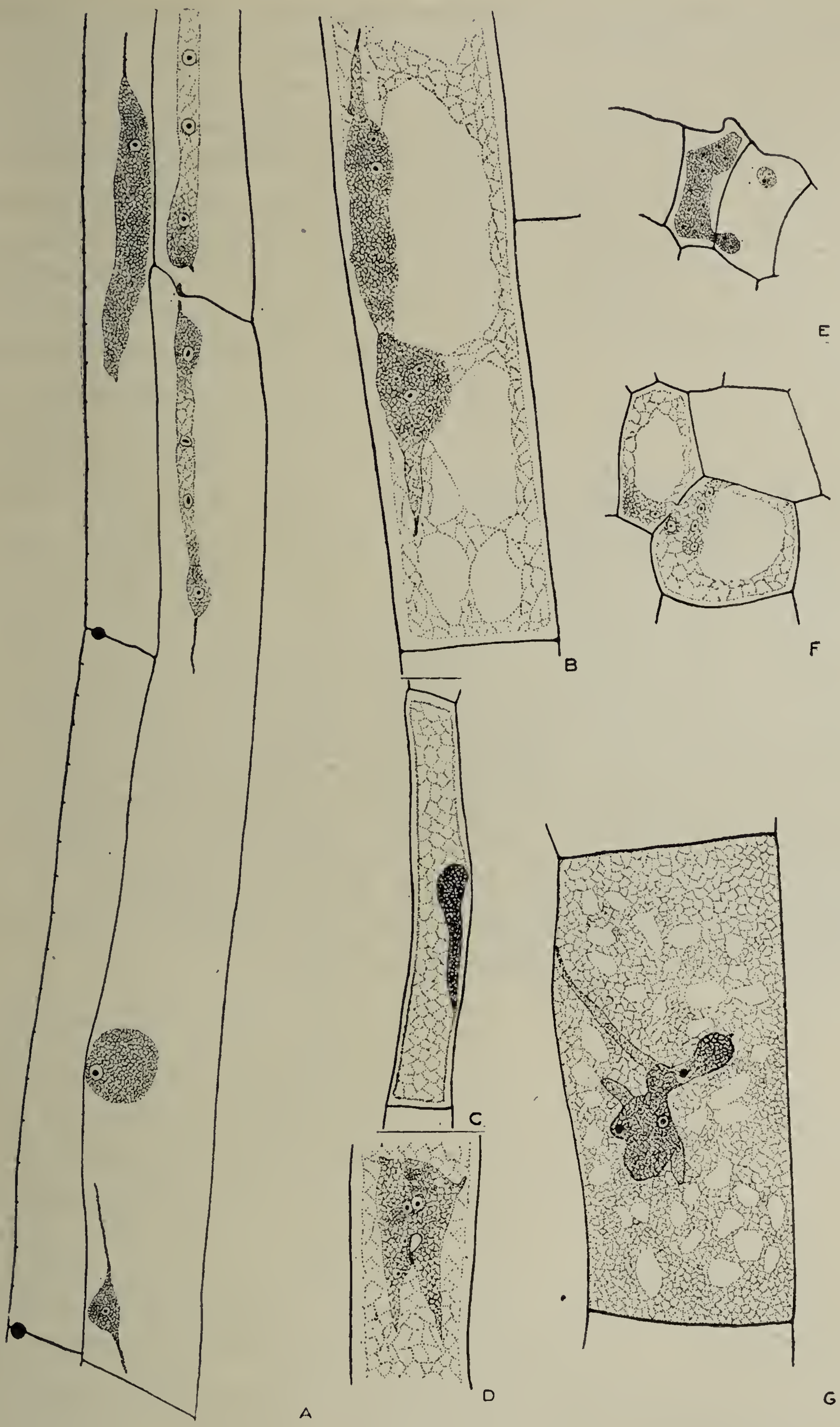

FIG. 105. AMŒBÆ IN THE HOST CELLS

A, B, C, D, and G, Amœbæ, with pseudopodia, in recently infected roots. E, Amœbæ in adjoining cells, divided only by the cell walls; this is evidently a case in which penetration occurred, altho no connecting strands are visible. F, Amœba penetrating the cell wall. × 110

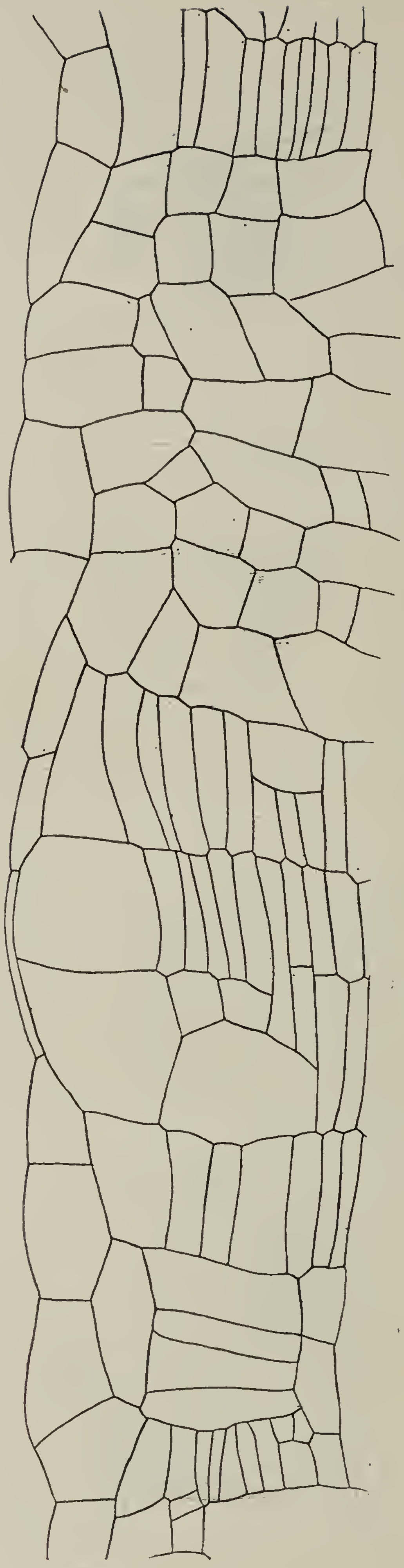

FIG. 106. FORMATION OF "KRANKHEITSHERDE"

All the narrow elongated cells are still uninvaded, but they have increased greatly in number thru outward pressure of the hypertrophied cells. × 110

not happen, as may be seen by examination of cross-sections. Besides, if it did, it would explain only the presence of longitudinal rows of diseased cells, and not necessarily the whole "Krankheitsherde." For example, in figure 106 the original cortex was five cells wide. That is the same number as is found in the "Krankheitsherde." These are connected by a single row of diseased cells. How could the diseased area have originated without direct migration and still show no radial hyperplasia?

Woronin's (1878) view is that the parasite, taking advantage of the pits found in the parenchyma, goes directly from cell to cell and thus thruout the root, much like *Spongospora subterranea* in tubers as described by Kunkel (1915) except that the organism in the potato is intercellular. To Nawaschin (1899), who saw no actual passage thru the walls, it seemed too difficult a task for the amœba to break thru the plasma membrane; hence he decided that there is never any migration, the distribution being due entirely to rapid division of diseased cells.

Maire and Tison (1909, 1911) and Schwartz (1910, 1911, 1914), who have made observations on the other Plasmodiophoraceæ, explain the scattered diseased areas as due to infection of the apical cells which by subsequent divisions gives rise to the diseased rows so often seen. Schwartz (1911), in spite of the fact that he saw pseudopodia in *Sorosphaera graminis* extending thru the cell wall, makes the statement that he does not believe species of any of the genera show direct migration. He explains his skepticism on the ground that he never saw any accompanying nucleus in these pseudopodia.

Lutman (1913) figures actual passage thru the wall. He believes that the amœbæ are transferred in the cortical tissue both by penetration and by division of the host cells.

It is altogether possible to cut a large number of sections without obtaining any definite clue as to the mode of migration from the root hair to the cortex or the medullary ray, for in the later stages the cell wall acts as a perfect barrier. In view of this fact, Nawaschin might have done enough staining to complete his carefully planned cytological problem without once cutting a root so recently infected that the passage from one cell to another could be detected. During the first two years of the writer's study, only roots that showed evident hypertrophy were used and none of these gave any evidence of such a passage. As soon as the smallest rootlets were sectioned longitudinally, penetration could be observed. It is true that it never appeared abundantly; yet it might have been there and not noticed, for the opening in the wall is so minute and the strand which passes thru is so nearly hyaline that only deep staining will make it apparent under the microscope (fig. 105, F, page 437). There are numerous cases in which it is probable that such a migration has taken place but the connecting strand cannot be seen (fig. 105, E).

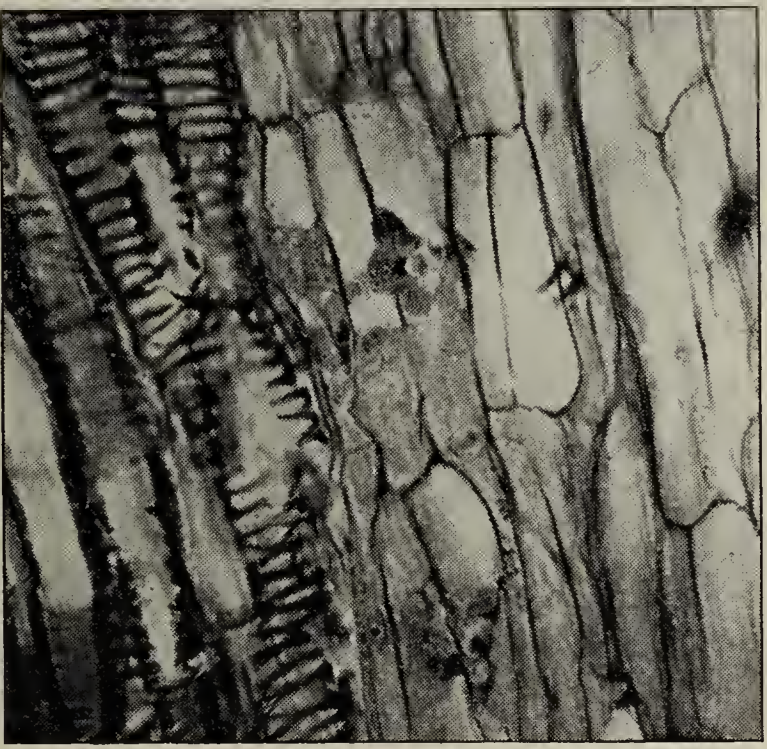
Fig. 107. AMŒBA EXTENDING FROM ONE CELL INTO ANOTHER

The objection has been suggested that these strands are merely the remains of a thread which was not severed when the wall was laid down between two dividing cells. This may be true in such cases as are represented in figure 107, but in other cases the position of the cells precludes the tenability of such an assumption.

Another argument in favor of cell-wall penetration is the shape of the amœba in the initial stages of invasion as compared with that in later stages. When the smallest rootlets, containing only a few diseased cells, are sectioned longitudinally, the amœbæ are usually seen to be elongated and often have pseudopodia extending in different directions. This is never true in a more advanced stage. The amœbæ are then nearly spherical and remain stationary in the cell. This difference is seen on comparison of figures 105 and 108.

The small offspring at once begins to grow in the newly invaded cell, the process of penetration being repeated while the tissue is still young. From this statement, however, it is not to be inferred that all this occurs while there is no cell division, and that each daughter cell in turn does not become infected. Cell division certainly does take place from the beginning, first in conjunction with penetration and later alone. The result of both methods of invasion is illustrated by figure 100, B (page 430), which shows a row of eight diseased cells. They extend the same length as three healthy cells. Their relative lengths had been attained before infection occurred; therefore the organism must have passed thru at least two walls, while cell division accounts for the remainder.

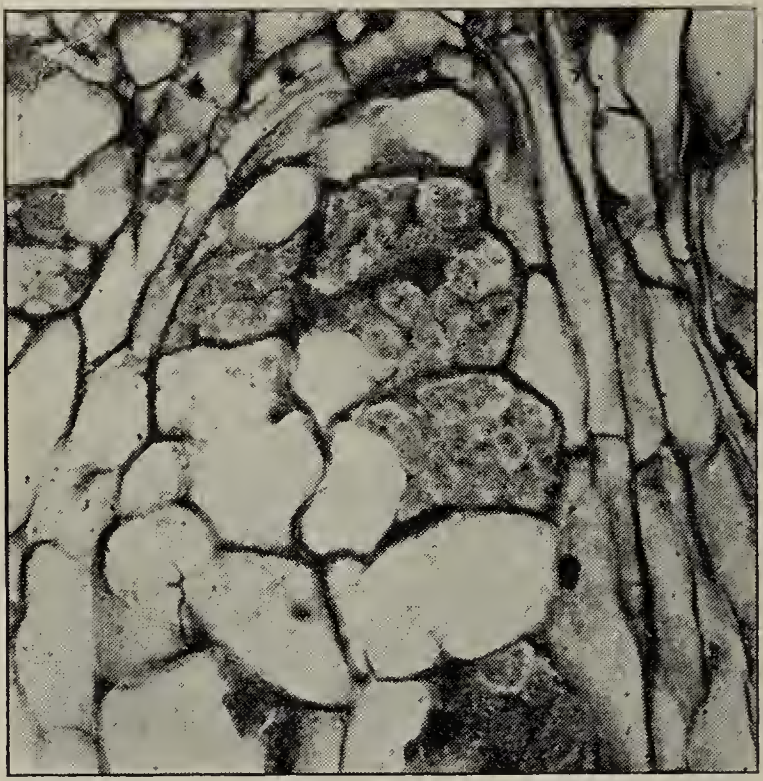

FIG. 108. HOST CELLS FILLED WITH CLOSELY CROWDED AMŒBÆ

This leads the study to the process of "Krankheitsherde" formation. The whole subject has usually been dismissed with the arbitrary statement that a single cell becomes diseased and then a closely packed group of cells finally results by repeated divisions both anticlinally and periclinally. A cursory study of cross sections would naturally suggest such an explanation, for undoubtedly the diseased areas are arranged in more or less distinct groups. But again longitudinal sections of young and recently infected rootlets may be used to clear up the difficulty and show the initial stages of a typical "Krankheitsherde."

The impression must be avoided that passage thru cell walls is so frequent that a single root-hair infection will suffice to spread the organism thruout the entire affected part of the root. There must be repeated infections, since the amœbæ never migrate far, as the longitudinal sections show. They may enter in almost a straight path as far as the endodermis. The invaded cells may then divide or merely increase in size. Meanwhile the adjoining healthy cells show abnormal division. Nawaschin (1899) explains this hyperplasia on the part of non-invaded cells as due to the mechanical outward pressure of the much-enlarged diseased cells. Eleven rows of uninvaded cells adjacent to a "Krankheitsherde" are shown in figure 106 (page 438); in the healthy part of the root there are only five rows of cells.

For some unknown reason the amœba in some cases may not penetrate as far as the endodermis, but, after having reached a certain row of the cortical cells, it may pass upward or downward in that row, cell division taking place as fast as invasion occurs. This produces such rows of cells as are illustrated in figure 100. The vertical direction may be changed at any time and at frequent intervals to a horizontal one, and the adjacent rows thus affected at once begin cell division in each direction. The result is a true "Krankheitsherde." Any one of these diseased rows, or several of them, may extend beyond another group of healthy cells, from which the organism again moves horizontally. This will cause a second "Krankheitsherde," above or below the first and separated by the length of one or more healthy cells. This is illustrated in figure 106 better than it can be described. A single infection may in this manner give rise to from one to probably six "Krankheitsherde," with the intervening uninvaded cells much increased in number over those in the normal tissue.

It has already been pointed out why this longitudinal movement is interpreted as the result of cell-wall penetration instead of as being due to mere division. The diseased area shown in figure 106 is only five rows of cells in width. The perfectly normal tissue of the same root shows exactly the same number of rows. There has been no periclinal division, and therefore direct migration must have taken place.

All this occurs when the root is only a few millimeters in diameter. For some reason the walls finally become impenetrable, and the amœbæ become more nearly globose and later are transformed into masses of spores.

SPORE FORMATION AND SIZE

For the purpose of this discussion the nuclear phenomena need not be included. The generally accepted explanation of a true mitotic division followed by vacuolar separation into individual uninucleate spores is well known. This separation is supposed to take place almost simultaneously, but stained sections do not always show this to be true. Stages from the amœba to the mature spore are represented in figure 102, D (page 434). In this case there were repeated successive separations instead of simultaneous fission, so that each amœba is divided into two, then four, and so on until no two nuclei longer remain together. The unstained spores in figure 102, A, show the same method of formation. They may then be hexagonal or irregular in outline, and much larger than when mature, but they soon become spherical.

It was surprising to note the wide difference between the actual size of the spores, and the measurements (1.6 μ) given by Woronin (1878) and nearly all succeeding authors. Molliard (1909) gives the diameter of the spores as from 1.8 to 2.2 μ, and Pinoy (1907), altho he does not state directly, says in speaking of swarm-spores that they are from 3 to 4 μ in diameter.

The measurements made in connection with the present experiments agree more nearly with those of Pinoy for the swarm-spores. The spores in formation, when not yet spherical, measure from 2.5 to 6.9 μ in diameter, being much more variable than those that are older. The smallest mature spore measured was 1.9 μ, and the largest was 4.3 μ. These measurements include not only living spores but also those stained in various ways. The average was 3.3 μ.

A SIMILAR ORGANISM

For some time the writer was at a loss for an explanation of the occasional presence of from two to twelve strange nuclei in certain root hairs and epidermal cells (fig. 109, A). These are from 3 to 4 μ in diameter, being smaller than the nuclei of the host cells. The nucleoli have a much denser content than those of the host cells, and are much smaller and less prominent. They appear to be entire swarm-spores containing no visible cytoplasm; however, they do not resemble those of *Plasmodiophora Brassicae*, being larger, and, most important of all, not having the hyaline zone about the nucleolus which is so characteristic of the latter.

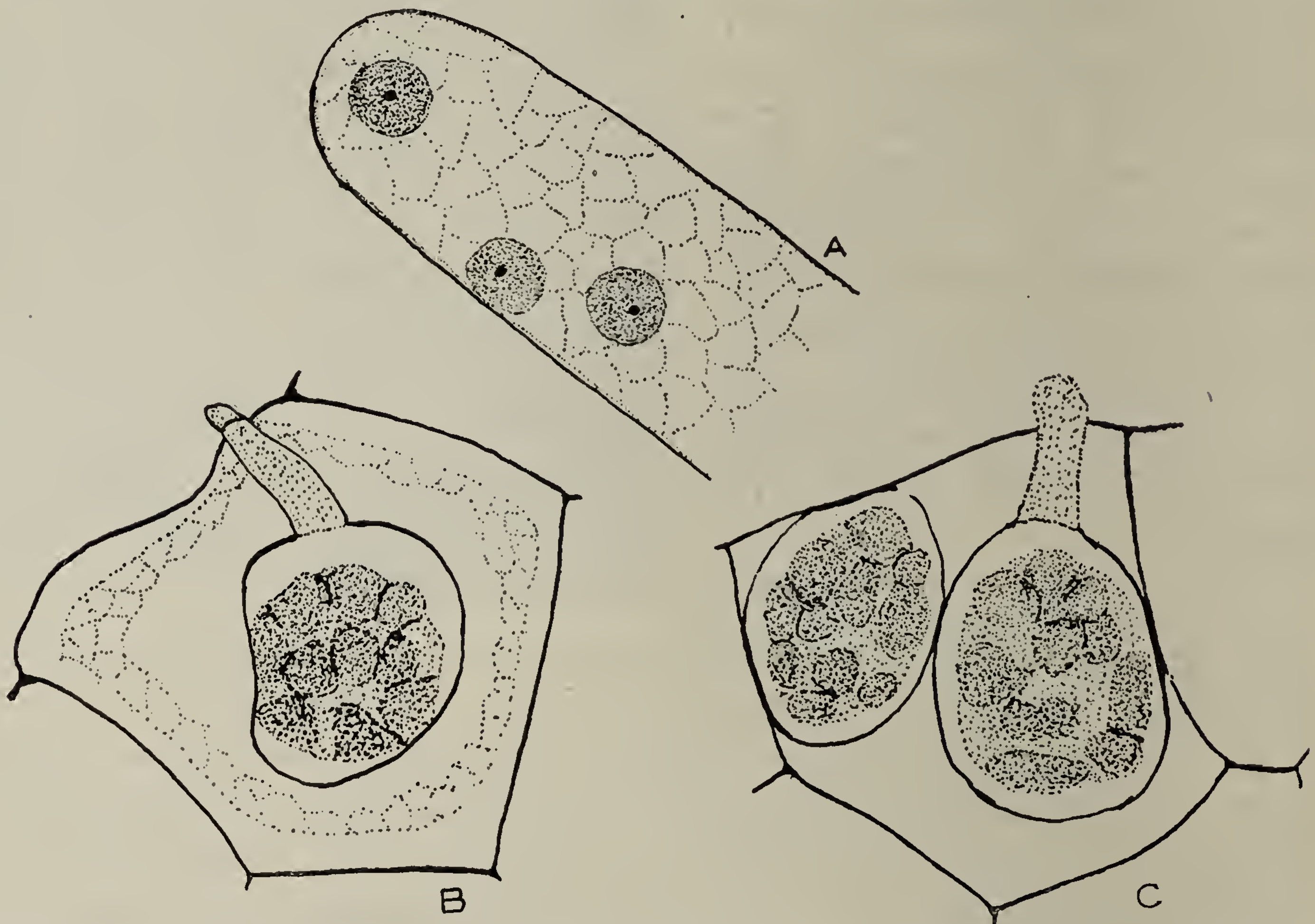

FIG. 109. AN UNKNOWN ORGANISM ASSOCIATED WITH PLASMODIOPHORA BRASSICAE

A, Nuclear-like bodies in a root hair, probably swarm-spores of *Olpidium Brassicae*; B and C, an unknown organism in the epidermal cells of a cabbage root, probably *Olpidium Brassicae*. × 800

Furthermore, amœba-like bodies are found in the epidermal cells or the layer next to them, which also look very much like Plasmodiophora but seem to be inclosed in a delicate wall. Stages have been found in which each of these bodies has an appendage, or neck, which protrudes thru the outer epidermal cell wall (fig. 109, B, C). The organism compares very closely with that described by Woronin (1878) as *Synchytrium Brassicae* and later by Dangeard (1886) as *Olpidium Brassicae.* Positive proof of its identity is lacking.

The chytrid never produces any hypertrophy or other outside symptoms by which a diseased plant can be recognized, so that specimens were found only accidentally. For this reason it was impossible to study the swarm-spore stage or the details of the life history of the organism.

The organism evidently enters by way of the root hairs, and never penetrates far into the host. None of the invaded cells are changed in size or general appearance. Even the invaded root hair does not have that slight enlargement which has been mentioned in connection with the entrance of the uninucleate amœba of *Plasmodiophora Brassicae.*

The fungus can infect a plant that seems perfectly healthy. At least it is not a saprophytic form following the clubroot organism, as roots were sectioned which showed it alone.

BACTERIA IN RELATION TO PLASMODIOPHORA BRASSICAE

Pinoy's (1902, 1903, 1905, 1907) work with Myxomycetes in their relation to bacteria, and his subsequent suggestion that there is a true symbiosis between the two, represent a very interesting phase in the study of Plasmodiophora. It has long been held that certain saprophytic slime molds feed on accompanying organisms, and the data at hand seem entirely plausible. Lister (1894) has seen the ingestion of bacteria by active swarm-spores. The experiments of Vuillemin (1903), Nadson (1901), and Potts (1902) show that *Dictyostelium mucoroides* Bref. feeds directly on bacterial colonies and destroys a large number of these at fruiting time.

The general conditions of subsistence governing saprophytic forms and those controlling parasitic organisms are not the same, however; so that from *a priori* reasoning it would seem justifiable to say that *Plasmodiophora Brassicae* needs no concomitant organism in its life cycle. Yet the case is not so clear, since, on examination of nearly every root that has been diseased for some time, such an organism is found to be present. When the surface of these roots is sterilized and placed in agar, they may show no indication of bacteria until they are cut in two and the fresh surface is placed in contact with the medium. Moreover, E. F.

Smith (1911) and Eycleshymer (1894), both careful workers, state that they saw these bacteria. This is also in accordance with what Maire and Tison (1911) claim to be true for certain parasitic slime molds that are able to ingest unicellular algæ present in their aquatic host; and with what Kunkel (1915) has demonstrated in the case of *Spongospora subterranea* grown on agar in which pure cultures of plasmodia become abnormal and die, while those with which bacteria are present live and thrive.

All of Pinoy's (1905) experiments appear to corroborate his idea that a coccus form enters the root with the swarm-spore and lives in constant association with the parasite thruout its entire life cycle. He stained sections of the root and observed bacterial forms within the cells. They appeared so much like parts of the cell contents that the microscopical analysis had to be accompanied by cultural study. For this he procured diseased roots of *Brassica sinensis* measuring from eight to ten centimeters in diameter, seared the outside, and cut plugs from the interior by means of a flamed pipette. When these plugs were planted in agar media, numerous colonies of bacteria soon appeared. To prove that these organisms were necessary for the development of the myxomycete, Pinoy placed spores of *Plasmodiophora Brassicae* in a large number of test tubes containing sterilized extract of roots. In two tubes the spores were accidentally not associated with bacteria and they failed to germinate, while in all the other tubes the spores did germinate.

Pinoy's results are interesting, altho the work does not appear to be extensive enough to warrant the conclusion he has drawn. The following experiments were undertaken by the writer in further quest for facts bearing on this problem:

Thruout three years of study almost five hundred petri-dish and test-tube cultures have been made from diseased roots of all sizes and ages, grown under various conditions and in widely separated localities. The ordinary method of procedure was to place the roots for ten minutes in mercuric chloride 1-1000; then, after rinsing them several times in sterilized distilled water, to break the roots open and remove bits of the diseased tissue from the broken surface by means of a flamed scalpel. The bits of roots were placed in a sterilized petri dish, where they were teased apart in a few drops of sterilized distilled water. Two successive dilutions were made, and these, together with the original drop in which the tissue had been crushed, were poured into nutrient agar media.

All the results were uniform in that no bacterial colonies were obtained from the roots with young swellings. From the medium-sized swellings occasional colonies developed; and from the larger galls, especially when the epidermis had been broken, numerous colonies always appeared.

The fact that only the small swellings show no contamination might be attributed to the penetration of the mercuric chloride. In order to avoid this source of error, the time of treatment was reduced from ten minutes to five, and even to three, or was dispensed with entirely, the roots being soaked for three hours in water that had been standing over calcium hypochlorite for two hours and then decanted. The results were the same.

Another possible hindrance to the appearance of colonies at first might have been the medium, which was nutrient agar. In order to eliminate this objection, later cultures were made both in potato agar and in a medium made from the extract of healthy cabbage roots like that used successfully by Kleimenov (1912). No bacterial growths were obtained.

Bacteria have been found in large roots similar to those that Pinoy used; but Pinoy obtained a coccus, while the most prevalent form in the cultures of the writer has been a very motile rod-shaped bacterium producing yellowish, opalescent colonies on the various media. In test tubes containing disinfected diseased roots this organism readily produces a soft rot and thus liberates the spores of the slime mold. It is well known that the epidermis is soon ruptured after swelling begins, and from all indications the conditions are propitious for the entrance of any organisms that may be in the soil. This is doubly true for any that find exposed cabbage tissue a favorable substratum on which to reproduce, as does evidently the bacterium mentioned above. These series of cultures tend to show that bacteria do not enter with the swarm-spore, as Pinoy (1905) believes, but that the disease must advance to a certain stage before the bacteria can gain entrance. The above experiments are perhaps in themselves not sufficient proof, especially since they bear on the negative side of the question. To these, however, are to be added the following data:

The writer has found that spores germinate better if they have been exposed to cold or to drying for a short time before being placed in a warm oven at a temperature of from 27° to 30° C.; and that the best medium tested is water that has been filtered thru muck soil. Accordingly diseased roots were washed, treated with either mercuric chloride or calcium hypochlorite, placed in sterilized, cotton-plugged test tubes, and left in the ice box for seven days. At the end of that time they were cut into pieces with a flamed scalpel and some of the sterilized muck filtrate was added, after which the roots were placed in the incubator for six hours. Before making mounts to examine the material, a loopful of the filtrate was transferred to each of two petri dishes, which were then poured with nutrient agar. This was done in order to determine with certainty whether or not bacteria were present. Germination was fully as good when the bacteria were not present as when they were. This is in direct opposition to Pinoy's (1905) statement that there is no development when the spores are not accompanied by a coccus.

Diseased cabbage roots were disinfected with either mercuric chloride or calcium hypochlorite; if with the former, they were then rinsed three times carefully in different tubes of sterilized distilled water; if with the latter, they were rinsed in muck-soil filtrate, which is acid and tends to neutralize any of the calcium compounds that might adhere to the roots and retard germination of the spores. All the roots were then either transferred to tubes of nutrient agar slants or embedded in agar in petri dishes. If at the end of a week they showed no signs of contamination, those in the petri dishes were placed on agar slants, after which all the roots were minced and left for another week in order to make sure that no bacteria were in the roots and had been liberated by the mincing.

Seeds of the cabbage were sterilized by the same method as was employed for the roots, but they were not rinsed in sterilized water when calcium hypochlorite was used. The seeds were planted in nutrient agar in petri dishes and the young plants were permitted to develop until they were free of the old seed coats. They were then placed in the tubes with the minced roots that showed no bacterial colonies, and a sufficient amount of the sterilized muck filtrate was added to insure spore germination but not enough to injure the small seedlings.

This process, tho complicated and long, seems to fulfill all the requirements that carefulness demands; and in the three series tried, from five to twenty per cent of the cultures were free from bacteria. The chief difficulty lies in the fact that there is such a narrow margin between spore formation and bacterial invasion that it is hard to select swellings which are neither too young to contain mature spores nor yet so old that bacteria have entered. One objection to the experiment is obvious. There is no way of determining contaminations except by the absence of colonies on the agar where the roots have been minced and on which the seedlings grow. Yet it seems hardly possible that bacteria can be present thruout all these operations and not come into contact with the medium. Besides, where no bacterial colonies appear, the plants grow more vigorously, produce larger roots, and show infection sooner than in the contaminated tubes. Swellings apparent to the naked eye were formed at the end of five days the first time the experiment was tried. When the plants were fixed, sectioned, and stained, they showed amœbæ in the cortex as well as in a large number of root hairs; all of which tends to discount Pinoy's (1905) belief that there is no development of the parasites without a concomitant bacterium.

Pinoy based his conclusions in part on the evidence presented by stained sections. Apparently he studied sections of large roots, since the roots that he received from Mangin were evidently eight or more centimeters in diameter. The writer was unable to procure thionine, the stain that Pinoy used, but he tried both Ziehl's carbol fuchsin and Kuehne's carbol methylene blue, which have always given good results in staining parasitic bacteria in other tissue. Parts of small, slightly swollen roots, as well as pieces of larger roots (of which some were still normal in color and others had begun to turn black), were fixed in Carnoy's fluid, consisting of glacial acetic acid and alcohol. The small, slightly swollen roots after staining showed no signs of bacteria. Pinoy (1905) states that cocci appear as very refractive bodies among the amœbæ. In this experiment, the hila of partly corroded starch grains (fig. 110, A) appeared in several instances as spherical, brightly stained bodies; but they could hardly be mistaken for an organism, as the same effect is shown in healthy cells in which entire starch grains may be seen.

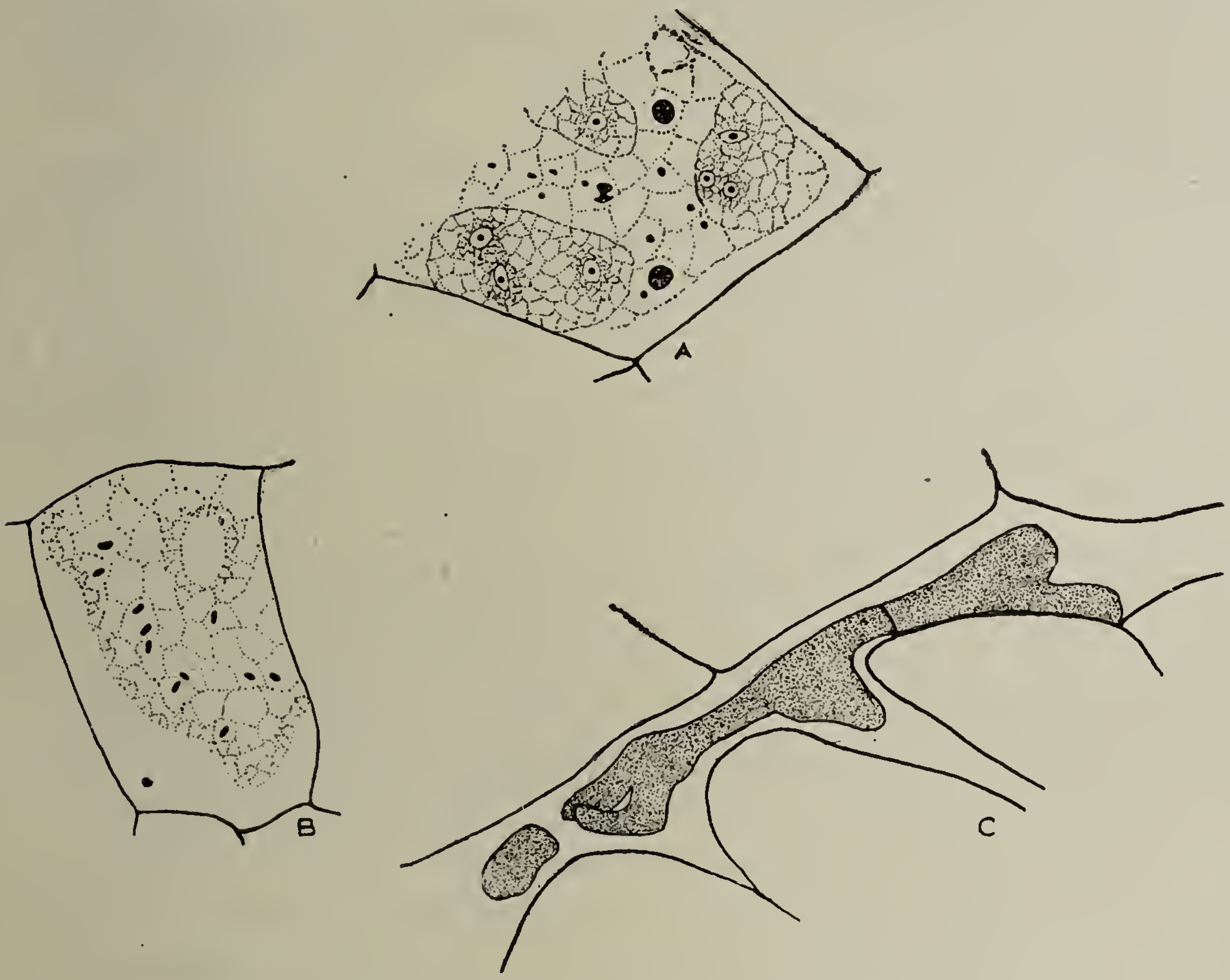

FIG. 110. SAPROPHYTIC ORGANISMS IN DISEASED TISSUE

A, Partly corroded starch grains between the amœbæ, the refractive hila being the only visible part in some of them; B, bacteria in a cell of diseased tissue; C, mycelium of a saprophytic fungus in darkened diseased tissue. × 800

The older, diseased tissue that has not yet turned dark presents a somewhat different appearance from that of the youngest swellings. The epidermal cells are torn in many places, and rod-shaped bacteria (fig. 110, B) are found both within and between the cells. Many of these cells show broken passages in the walls where the organism could easily have entered.

In a blackened root the only additional change that can be recognized is the presence of hyphæ. This blackness is almost a true criterion of the effects of a fungus, for the bacteria seldom, if ever, produce any pronounced discoloration (fig. 110, c).

It is not altogether a new phenomenon to find other organisms following parasitic slime molds. For example, the earlier writers who described *Sorosphaera Veronica* regarded it as a rust because of the mycelial threads which, according to these investigators, are constantly present. Maire and Tison (1909) prove with but little difficulty that the fungi are merely saprophytic attendants. The case is almost identical with that which Schwartz (1914) cites for species of Ligniera with which typical mycorrhiza are continual associates.

It has been shown that non-parasitic myxomycetes undoubtedly make use of bacteria. It seems, therefore, altogether reasonable that when a facultative saprophyte is grown under conditions to which *Spongospora subterranea* was subjected by Kunkel (1915), it will assume the habits of a saprophyte. As far as this discussion is concerned, the only question is whether *Spongospora subterranea* still utilizes bacteria when in the potato tuber.

Objection may be found to each of the above experiments taken alone. When considered together they cover the subject thoroly enough, and coincide so fully in their results that it seems logical to draw the conclusion that *Plasmodiophora Brassicae* has no need for the bacteria and that the latter are merely attendant saprophytic forms which incidentally help to set free the spores of the parasite. Only two factors favor Pinoy's theory. One is the presence of bacteria in most roots in which any considerable swelling has taken place; the other, the fact that there is a smaller number of different species of organisms present than might have been expected. Almost invariably the rod-shaped bacterium forming opalescent colonies on nutrient agar was the only one isolated. The facts, however, that spores can germinate in sterilized media, that infection can occur on seedlings in test tubes on nutrient agar where no bacterial colonies are present, and that recently infected roots never show bacteria either when tested in culture or under the microscope after staining, would seem to offset any evidence that heretofore has been adduced to the contrary. Therefore it seems evident that *Plasmodiophora Brassicae* is an obligate parasite, and, as such, needs no other food supply than that furnished by its host.

SUMMARY

Neither the motility of swarm-spores nor the action of winds is an important factor in the dissemination of *Plasmodiophora Brassicae*.

Spores germinate better after a slight rest period and in such a medium as muck-soil filtrate. Each spore produces one swarm-spore, which, if not supplied with a host, develops no further.

It is difficult to stain the flagella of swarm-spores, but if they are first killed instantly with fumes of osmic acid fairly good mounts can be obtained.

Penetration takes place thru the wall of the root hair while the organism is in a uninucleate stage. The root hair at once shows hypertrophy. The amœba increases in size as it passes rootward, and finally, by direct cell-wall penetration as well as by the division of the host cells, the pathogene is distributed thruout the cortical tissue.

The spores are not always formed by simultaneous vacuolar divisions of the amœbæ, there being cases in which they are produced by successive divisions while the adjoining amœbæ may still be in the nuclear stage.

Aside from *Plasmodiophora Brassicae*, there is often present another organism, which causes no hypertrophy and which is probably *Olpidium Brassicae* (Wor.) Dang.

In the experiments to determine the relation of bacteria to *Plasmodiophora Brassicae*, a large number of isolations were attempted, diseased tissues of all stages were stained, spores were germinated in sterilized media, and infections were secured in test tubes under aseptic conditions. All this points to the fact that the bacteria do not enter the host as soon as the slime mold does, but follow only after there has been enough enlargement of tissues to rupture the epidermis. Consequently the bacteria can be of no vital importance in the nutrition of the parasite.

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THE POPLAR AND WILLOW BORER

ROBERT MATHESON

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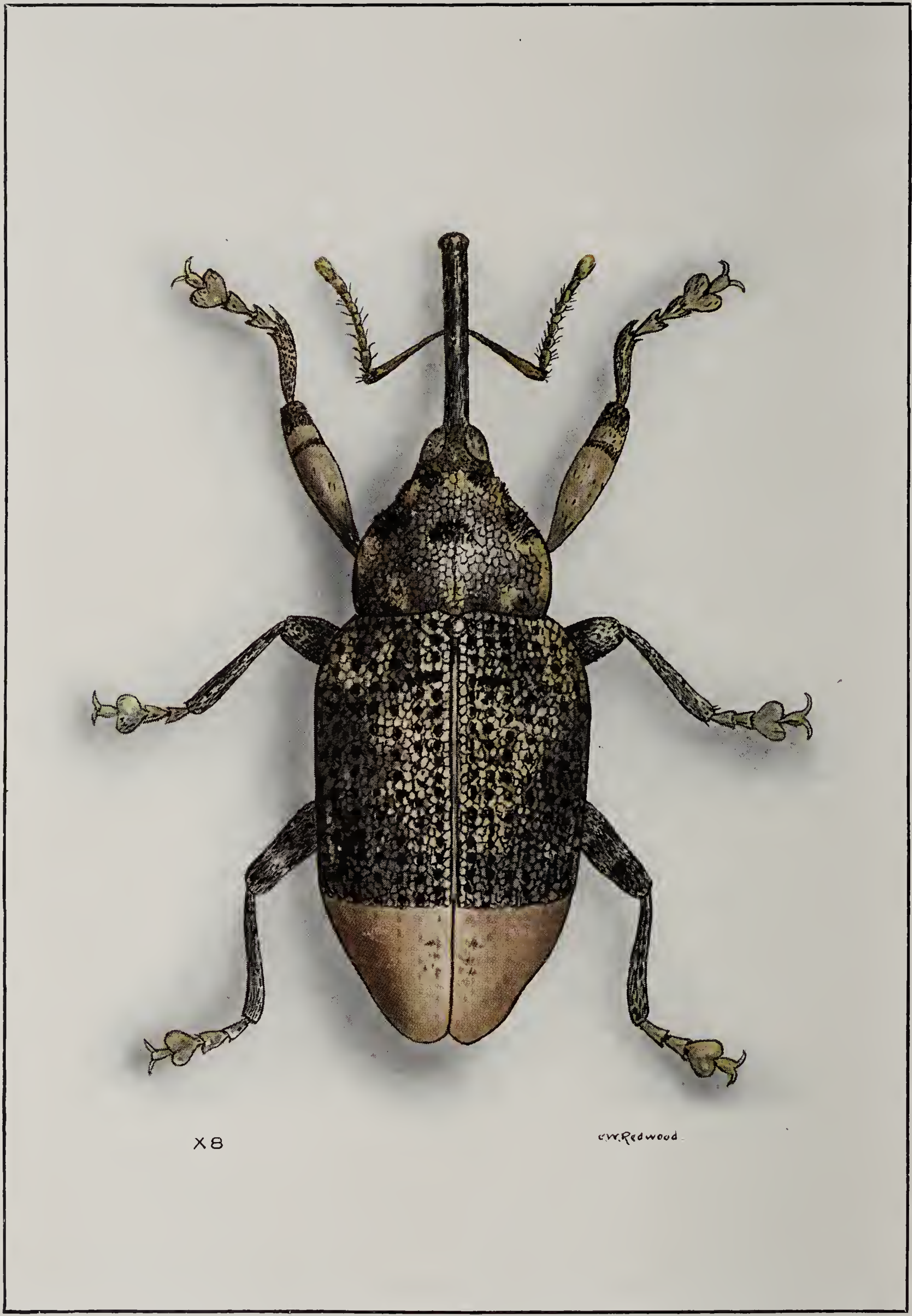

THE POPLAR AND WILLOW BORER
(Cryptorhynchus lapathi)

THE POPLAR AND WILLOW BORER

(*Cryptorhynchus lapathi* Linnæus)

Order, *Coleoptera* Family, *Curculionidæ*

ROBERT MATHESON

Ever since its introduction from Europe, in 1882, the poplar and willow borer or weevil has been a serious pest, not only in nurseries in the eastern part of the United States but also to the basket willow industry and to poplar and willow trees used for landscape planting. During the past ten to twenty years the weevil has become so abundant in many eastern nurseries that in many cases the nurserymen have almost abandoned the raising of carolina and other species of poplars to supply the demand for a rapidly growing shade tree. Also many young groves of poplars have been seriously injured, while large shade trees have been rendered unsightly by the breaking off of branches that have been so riddled by the boring of the larvæ as to be unable to resist high winds.

As this beetle is largely distributed through infested nursery stock, it would seem that the most efficient means of reducing the injury that it causes would be by controlling its work in the nurseries. If nurserymen could furnish trees known to be absolutely free from the pest, its further distribution would be restricted, and means could then be adopted to control its activities where it is at present causing serious injury. During the past three seasons the writer has conducted experiments which have proved very successful in controlling this pest under nursery conditions. These experiments are discussed in the present bulletin, which also gives a biological account of the insect.

HISTORY OF THE SPECIES

In Europe

The poplar, willow, or alder snout beetle, the *Erlenrüssler* of German writers, is a European insect. For centuries it has been a pest to alders and willows in Europe, and it has been the subject of many entomological papers.

Linné (1758) described the adult in his *Systema Naturæ*, giving as its host plant *Rumex lapathi*. Curtis (1791) published the first account of the natural history of the beetle. He found the larvæ injuring ornamental willows in his garden. He first observed the work of the beetle on *Salix viminalis* in 1780, and after a few years of study succeeded in finding all its stages except the egg, which he supposed was laid under the bark or in crevices resulting from injury. His figures of the various stages of the insect are the first ever published. Paykull (1792) records the beetle as injuring Salix species, and also refers to Linné's statement that dock (*Rumex lapathi*) is one of its host plants. Bechstein and Scharfenberg (1804) quote from Curtis's work, and also refer to the injuriousness of the beetle in Germany.

The insect is recorded in all the early systematic works dealing with the snout beetles (Rhynchophora), but no biological data are added. Ratzeburg (1839) records alder as one of its host plants, stating that in Silesia the beetle is known as the alder destroyer (*Erlenwürger*). Nördlinger (1856) records the insect as doing serious damage to young birches from five to eight feet high, their tops breaking off after having been seriously injured by the numerous larval galleries.

Westwood (1863) describes a serious outbreak of the beetle in ornamental willows in Essex County, England. Ratzeburg (1868) gives a much more extended account of the beetle and its injuriousness throughout the forests of Germany. His account of its life history is incomplete, though he gives many details as to its food plants and habits. Altum (1881) records the beetle as doing serious injury to stands of white and of black alder in various parts of Germany, as well as attacking several species of willows. He does not clear up any of the various disputed points not well understood regarding the habits and life history of the insect. Judeich and Nitsche (1889), though they discuss the insect in some detail and list all its known food plants, leave the question of its biology in the same condition as they found it.

The beetle is discussed more or less in detail also in many recent European works on forest and shade tree insects, but no attempt has been made to clear up the many obscure points in its bionomics. Scheidter (1913) gives an extended account of its life history in various parts of Germany, and seems to have added considerable new biological data, much of it differing widely from that found in America.

In America

This European insect was first recorded in America by Juelich (1887), who collected a single beetle at Williamsbridge, New York City, in 1882. In 1887 he found willows infested by the insect at West Bergen, New Jersey. In the previous year Ottomar Dietz had collected a single specimen on Staten Island, so that at this early date the insect was established in the extreme southeastern part of New York and the northeastern corner of New Jersey. Smith (1891) reported its spread in New Jersey and the destruction by it of nearly all the clumps of willows, as well as many fancy ornamental trees, at Newark and Arlington.

Howard (1895) states that E. V. Wilcox sent him specimens of the beetle and the larva from Cambridge, Massachusetts, reporting that willows in that section were severely infested. Jack (1897) records the beetle as being very abundant about Boston and Cambridge, it having been present in the Arnold Arboretum for many years and at that time proving very injurious to many species of willows and poplars and to two species of birches. Up to that time it had been supposed that the insect was restricted to the eastern Atlantic border, but in 1896 Ottomar Reincke collected it near Buffalo.

The beetle has now become well established in the Eastern States but its westward and northward spread has not been very rapid. Burgess (1903) records it from Ashtabula, Ohio, in 1901; Bues (Bues and Sandsten, 1904), from two nurseries in Wisconsin in 1903; and Washburn (1904) reports receiving specimens from the extreme northwestern corner of North Dakota, where the insect had been introduced on nursery stock from New York. This stock had been first shipped to a Minnesota nurseryman, who in turn had distributed it, some of it reaching northwestern North Dakota. It is clear that the beetle was thus, in all probability, widely distributed in the Northwest.

Patch (1908) first observed the insect at Orono, Maine, in 1907, and in 1911 it was found also at Augusta and at Presque Isle. Forbes (1911 a) records the beetle from Chicago in 1908, where it was abundant and destructive throughout the city. He reports that it has not been found elsewhere in the State.

FOOD PLANTS

The poplar and willow borer has a fairly wide range of food plants. European writers record it as attacking the following species: alders — *Alnus viridis* DC., *A. incana* Willd., *A. glutinosa* Willd.; willows — *Salix caprea* L., *S. viminalis* L., *S. purpurea* L., *S. triandra* L.; poplars — *Populus alba* L.; birches — *Betula* species. Jack (1897) states that in America all the native willows except the slender-stemmed species are subject to attack. This is confirmed by C. S. Sargent, Director of the Arnold Arboretum at Cambridge, Massachusetts. Of the imported willows the following have been observed injured in the Arnold Arboretum: *Salix alba* L., *S. fragilis* L., *S. babylonica* Tourn., *S. pentandra* Linn.

The following species of poplars are also recorded as host plants: *Populus balsamifera* L., *P. deltoides* Marsh., *P. alba* L. Schoene (1907 a) records the following species of willows as host plants: *Salix lucida* Muhl., *S. caprea* L., *S. cordata* Muhl., *S. sericea* Marsh., *S. alba* L., *S. amygdaloides* Anders. In addition two species of birch are known to have been injured—*Betula pumila* L. and *B. nigra* L. These, however, are rarely attacked.

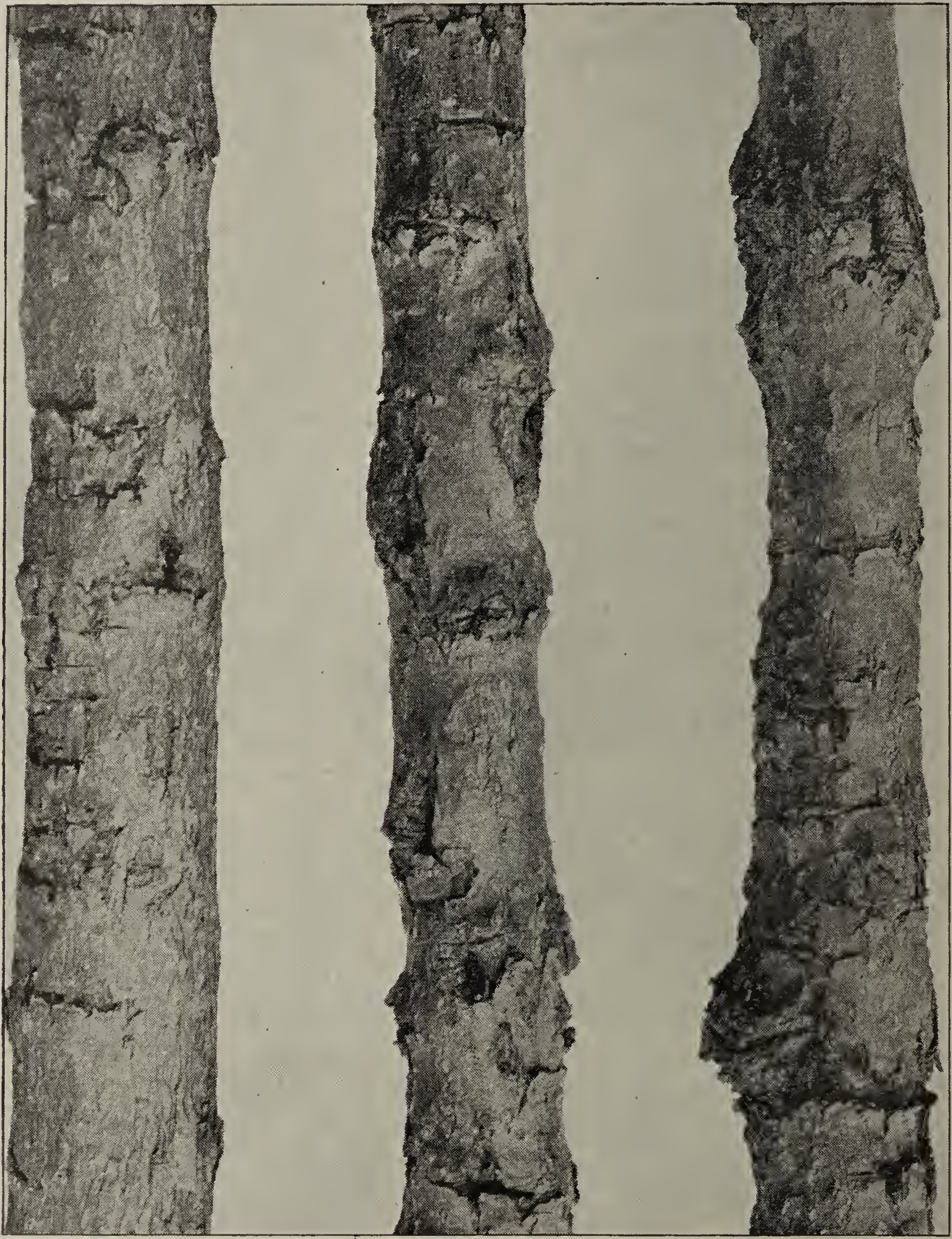

FIG. 111. TRUNKS OF SEVERELY INJURED CAROLINA POPLAR TREES, FIVE YEARS OLD

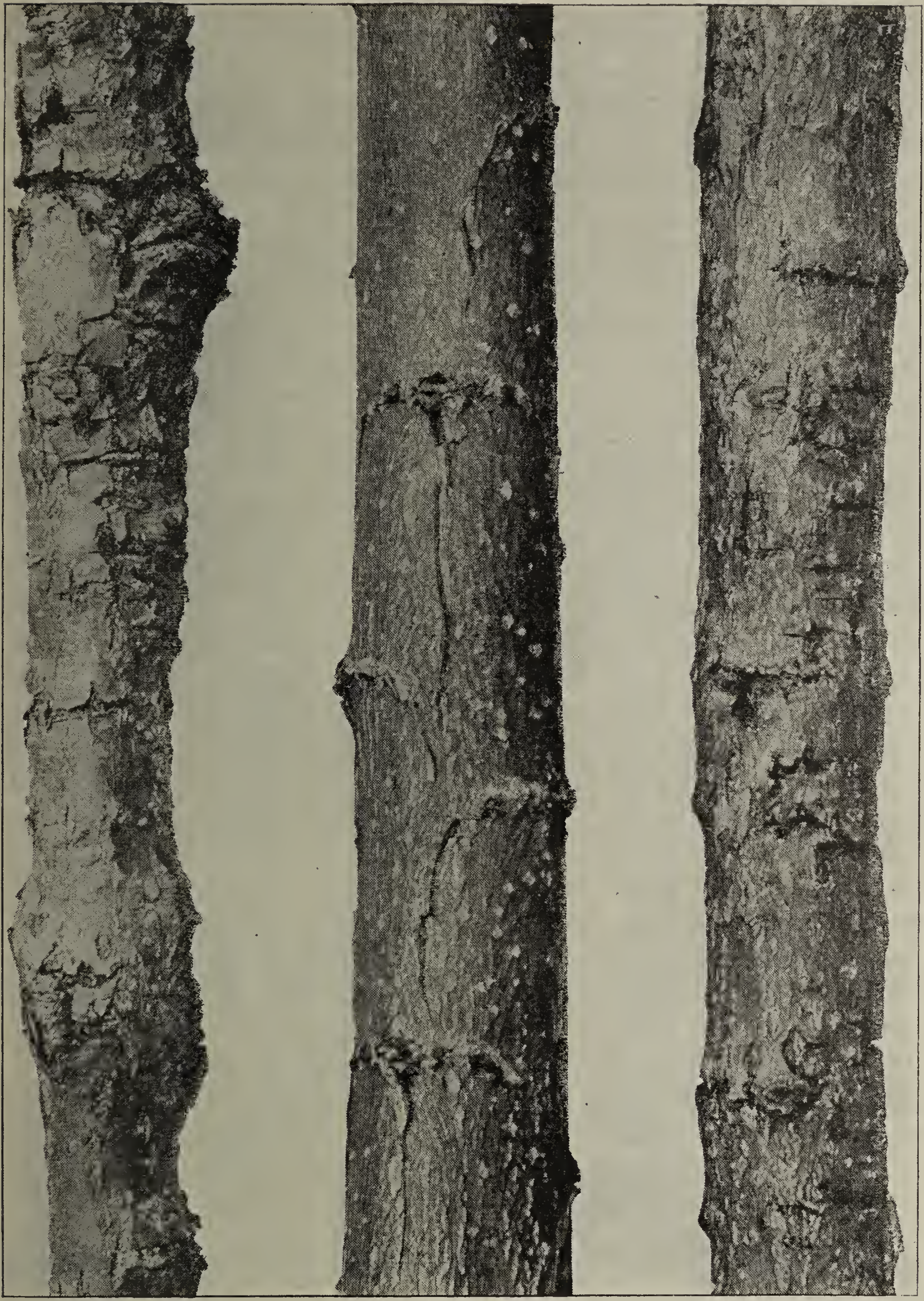

FIG. 112. INJURED AND UNINJURED POPLARS

At right and left, five-year-old trees, severely injured; an uninjured four-year-old tree in the center. All were grown under identical conditions in the experimental plot

ECONOMIC IMPORTANCE

The poplar and willow borer is of greater economic importance than has generally been supposed. It is a serious pest of practically all species of willows, and where the beetle is abundant the damage done is extensive. This is especially true of all varieties of ornamental willows. Also the production of basket willows is greatly reduced and in many cases stopped by the work of this insect. To many species of poplars it is very injurious, especially when the trees are young (figs. 111 and 112). In many nurseries the production of poplar stock has been discontinued owing to the prevalence and injuriousness of the pest.

The willows (Salix species) and the poplars (Populus species) are regarded generally as of not much value. However, many willows are used extensively in landscape work, not only for their quality of rapid growth but also for their beauty. Species native to this country line the streams and encroach on the boundaries of lakes and ponds, serving a very useful purpose as holders of the soil. The carolina poplar, though not looked upon with much favor as a shade tree, has been and is being planted rather extensively in recently developed areas. This is especially true in the Middle West, where the trees soon become suitable for lumber. Extensive plantings made from forty to fifty years ago in the Middle West, and also the great areas of cottonwood in the lower Mississippi Valley, are now being lumbered. The product finds a ready sale as lumber and commands a good price for excelsior. The carolina poplar is used also on sandy areas to keep the soil from being washed away.

The balm-of-Gilead poplar, which is used generally as a shade tree, is severely attacked by the borer. The branches serve excellently for the development of the insect, and in sections where it is prevalent scarcely a sound tree can be found. The branches, weakened by the larval burrows, are broken off by high winds and ice storms, rendering the trees unsightly.

In Europe the beetle has proved a pest to many species of willows, poplars, and alders. Many accounts are given of its destructive work, and there is no doubt that it is proving even a worse pest in America.

DISTRIBUTION

The beetle, recorded as having first appeared in America in 1882 (Juelich, 1887), has not spread very rapidly. It is at present known to occur from Maine west to Ontario and North Dakota and south to the District of Columbia. Throughout this area it is restricted to certain localities, and once introduced it does not spread rapidly unless carried by some agency. It is reported by Fletcher and Gibson (1909) as occurring at Dundurn, Saskatchewan, but nothing is known as to its spread in this province. It has not been found west of the Great Plains.

The preceding statement as to the general distribution of the beetle is based on letters received from various officials regarding the situation in their respective States. P. A. Glenn informs the writer that in Illinois the beetle is abundant about Chicago and occurs generally in the northern fourth of the State, while in the central and southern parts it has not been found. Dr. Fracker reports it as widespread in the nurseries of Wisconsin, where it has been found as far north as the shores of Lake Superior. Blatchley and Leng (1916) state that it has not yet been found in Indiana. Professor R. H. Pettit says that it is common in Michigan and probably occurs wherever the carolina poplar grows. In Ohio it seems not to have spread to any considerable extent since its first appearance there in 1901. It has not yet been found in Nebraska, South Dakota, Iowa, or Indiana.

In Canada, according to Caesar (1916), it is well distributed throughout Ontario and is also recorded from a few localities in the province of Quebec.

LIFE HISTORY

Although this beetle has been a serious pest in Europe for hundreds of years, its life history has never been fully investigated by European workers. Even at present there is the widest divergence between the accounts given by American and by European writers. This is brought out in detail in the discussion of the various activities of the different stages.

The adult

The poplar and willow borer (Plate XXII) belongs to the great group of snout beetles, Rhynchophora, and to the family Curculionidæ. This family contains an immense number of species, many of them very serious pests, including the common plum and quince curculios. The beetle measures from $\frac{1}{3}$ to $\frac{2}{5}$ inch in length, is robust, and is elongate-oval in shape. It is densely clothed with black and pale-colored scales, intermixed with erect, large, black bristles. The pale scales cover the apical third of the elytra and form an irregular band on the basal third; the underside of the prothorax and part of the legs are also densely clothed with them, and the remainder of the body bears a few scattering ones. The beak is curved, is as long as the head and the thorax, and lies when at rest almost completely concealed in a groove on the ventral surface of the thorax. The antennæ are elbowed and reddish brown, with an unsegmented club.

The beetles begin to appear during the latter half of July, becoming abundant in August. The writer found them present on poplar trees as late as October 7. After that date they could not be found on the trees in the writer's experimental plot. They are sluggish, very inactive insects, and move with a slow, lumbering gait. When they are disturbed, either by being jarred or by any sudden noise, they do not fly but feign death and drop to the ground, the beak and the legs being closely drawn against the body. They remain quiescent usually for a minute or two before attempting to crawl away. When handled they emit a squeaking noise, produced by the rubbing together of parts of the body. Though close watch for it has been kept, flight has not been observed, and no one has recorded the beetles as spreading by means of flight. Whether or not they are incapable of flight the writer has not been able to determine.

Shortly after the beetles emerge from the pupal cells they begin to feed, selecting young, tender shoots. The bark is punctured by the beak, a round hole being formed down to the cambium layer, on which the beetles largely feed. The beetles are voracious feeders, and when they are abundant the young one-year-old shoots may be so completely riddled by the feeding punctures that they shrivel and die. So far as the writer's observations go, the beetles do not feed on old bark, but confine themselves to the young and succulent twigs. Punctures in old bark are for the deposition of eggs, and these always appear some weeks after the beetles have been feeding.

The beetles do not seem to migrate to any considerable distance. Although the wings are perfect and apparently suitable for flying, yet the beetles have never been observed in flight or attempting to fly. In the nursery it is not uncommon to find one block badly infested, whereas a block somewhat distant may be only slightly injured. Change of location in the growing of poplars from year to year frequently makes a marked difference in the degree of injury. One block of about 15,000 trees in a large nursery near Geneva had an infestation of nearly 50 per cent in 1915. A block of about the same number of trees situated three-fourths of a mile distant showed in 1916 only a small infestation, 3.5 per cent, in the check rows. The beetles were abundant in 1915 in the block ready to be dug, and apparently they had confined their egg-laying operations to the poplars from which they had emerged. As this is true in all the cases coming under the writer's observation, it can readily be seen that a block ready to be dug, showing only a small percentage of infestation, may make an ideal center for distribution. As the nurseryman discards only severely injured stock, a block with such a low percentage of injury will practically have all the trees fit for sale, and in this way every egg deposited will be shipped away to start new infestations. When trees show considerable injury they are discarded and burned (fig. 113).

Although the beetles do not fly, yet they are undoubtedly well able to walk considerable distances. How far has not been determined, but they have been found a goodly distance from any of their food plants resting quietly on the trunks of various trees. This is especially true in the spring.

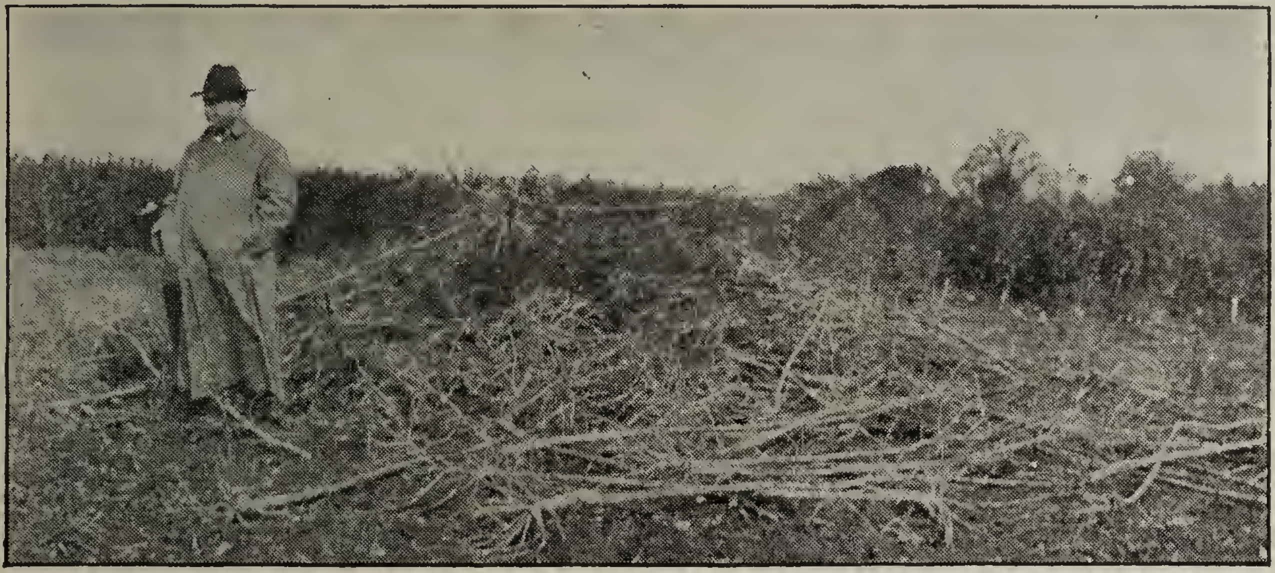

FIG. 113. A PILE OF DISCARDED CAROLINA POPLARS IN A NURSERY

Mating does not occur until ten days or more after emergence. This period is spent largely in feeding, and the beetles do considerable damage at this time to the vigorous growing shoots. Copulation occurs freely and a pair may remain several days in copula. Not only does mating last a considerable time, but it may be repeated again and again at different times.

Egg laying

Shortly after copulation the females seek out suitable places for the deposition of their eggs. They choose branches or parts of the trees more than a year old, and deposit their eggs in the corky parts of the bark. The eggs have never been found in one-year-old stock, but only in wood two years old or older. Favorite places for egg laying are lenticels (figs. 114 and 115), scars, bases of branches, injured areas, or about the base of buds where the bark is somewhat thick. With her beak closely applied to such an area the female beetle at once begins to eat into the bark. Gradually she deepens the round hole until her entire beak is buried, up to the eyes. The time required for this operation varies from a few minutes to thirty or forty minutes. At the bottom of the hole the beetle may round out two or three small lateral cavities, or she may be content with only one. In the majority of

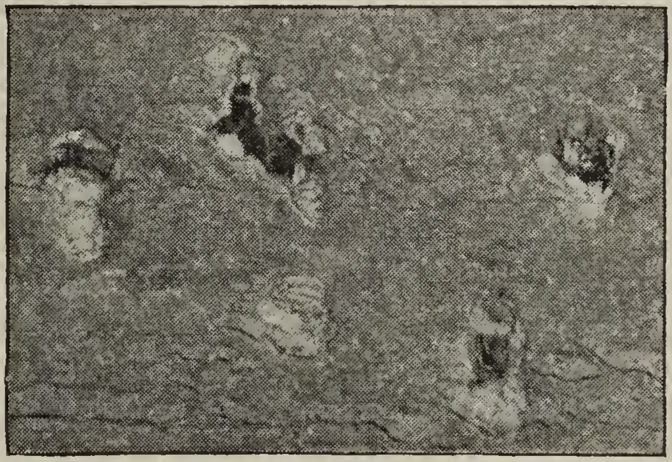

FIG. 114. EGG PUNCTURES AT THE SIDES OF LENTICELS

cases she does not dig out extra cavities, but uses the hole made for the deposition of but a single egg. When the cavity appears satisfactory, the beetle inserts her ovipositor and deposits from one to three or four eggs, depending on the kind of cavity dug. Then, reversing her position, she closely packs the eggs, both with beak and with antennæ, and covers them with fine pieces of the wood.

Egg laying continues from early August until October, but the number of eggs laid by a single female has not been ascertained. Whether or not, under New York conditions, all the females deposit all their eggs during this period, has not been finally determined. All American workers report that egg laying is finished in the autumn, and that the beetles do not hibernate but evidently die after the process is completed. In the writer's work no hibernating adults were found in the spring in the nurseries, though it should be understood that no extended search was made for them. In the writer's experimental plot, adults which evidently had hibernated were taken on April 21, May 1, and June 6, 1916. One was fresh and clean, apparently having but recently emerged from its pupal chamber. Though these were observed, they may be only rare occurrences rather than represent a normal mode of hibernation. Furthermore, egg laying was not observed in the spring, and in the treated plots there was no evidence that any eggs were laid after application of the various treatments. Had egg laying in the spring been normal, certainly the treated plots would not have shown such a high percentage of control.

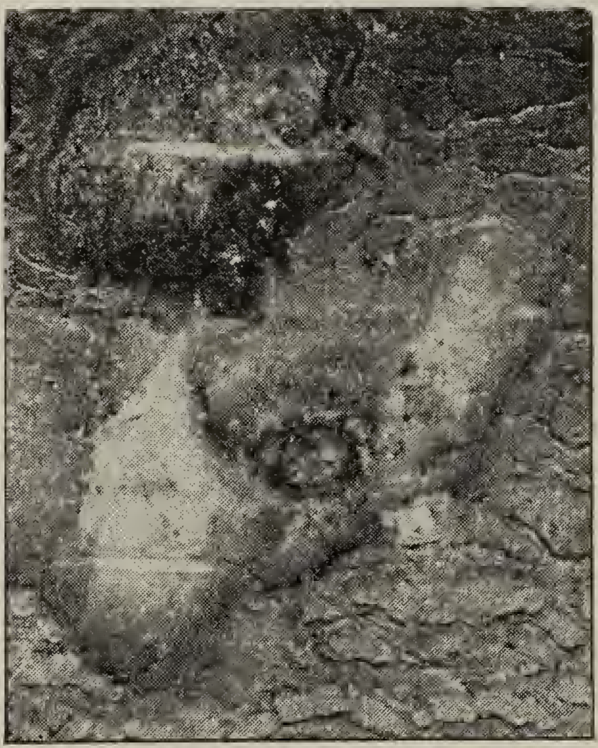
FIG. 115. EGG IN SITU, WITH OUTER PART OF LENTICEL CUT AWAY

The egg

The egg when laid is pure white in color but it becomes pale cream when a few days old. The shell is very thin and fragile, somewhat viscous, and without any distinctive markings. The egg is oval in outline, measuring 1.1 by 0.8 millimeters. The shape varies considerably, since owing to the softness of the shell it is easily modified by the shape of the cavity in which the egg is laid.

The egg stage lasts from eighteen to about twenty-five days, depending largely on weather conditions. The first observation of eggs hatching out of doors was on October 2, 1916. Undoubtedly many had hatched earlier, but from numerous examinations made during October the majority of the eggs had not hatched even as late as October 28. Early in November, 1915, the eggs began hatching in great numbers, and this continued until the latter part of the month.

The larva

When hatched, the young larva (fig. 116) is whitish in color and greatly resembles a miniature June-beetle grub except that the posterior end is the smaller and the larva is legless. It lies curled up in the egg cavity and begins at once to feed on the soft plant tissues. It is 1.5 millimeters in length, and 0.6 millimeter thick at its widest part. It is regularly transversely wrinkled, but the skin is nearly smooth except for scattering fine hairs. The head and the mouth parts are light brown except the mandibles, which are dark brown with black tips. The larva is cylindrical in shape, gradually tapering toward the posterior extremity.

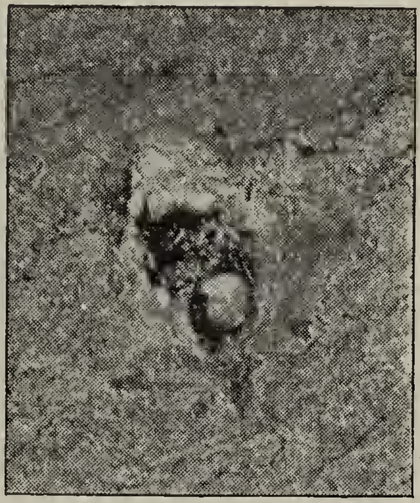

FIG. 116. YOUNG LARVA, JUST HATCHED

The larva feeds on the tender tissues of the plant and soon reaches the soft cambium layer. Externally the beginning of feeding can be easily recognized by the blackish, wet frass that fills the outer part of the egg cavity. Feeding continues until cold weather, the early-hatching larvæ attaining a considerable growth.

In the spring feeding begins as soon as the weather has become sufficiently warm, usually the first week in April. Moist frass, black to brownish in color, is forced out of the burrow as the larva feeds ravenously. The direction of the larval channels is nearly always around the trunk or the branch, and the larvæ feed at first exclusively in the bark and the cambium layer. As a result the tree is frequently girdled, especially if several larvæ are at work near the same place (fig. 117). The larval channels vary greatly in shape; some are cylindrical and girdle the tree, others are flat, irregularly shaped chambers, while the majority zigzag in various directions through the cambium layer.

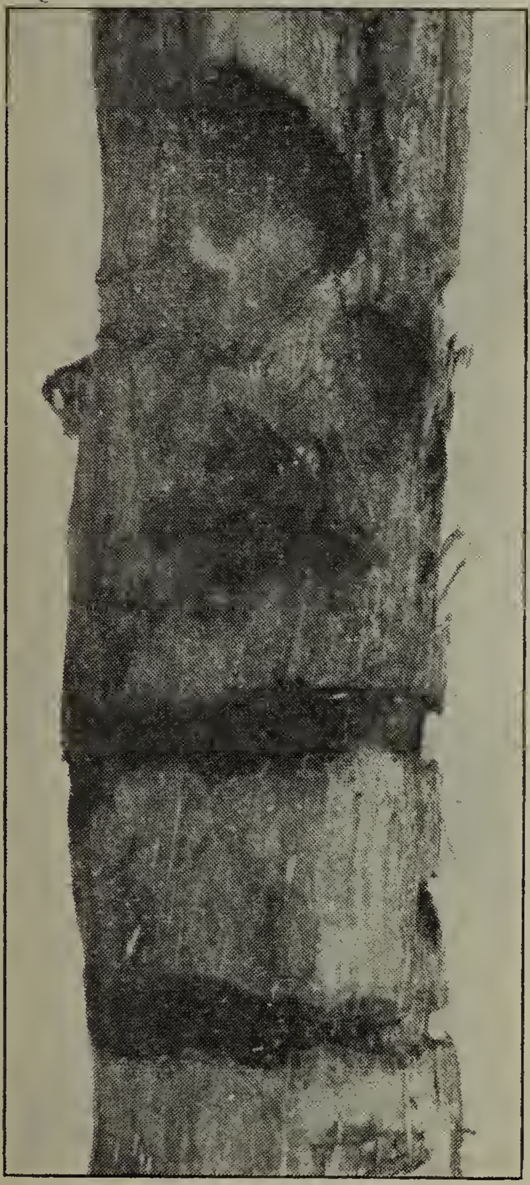

FIG. 117. CHANNELS MADE BY LARVÆ IN A YOUNG CAROLINA POPLAR TREE

As the larvæ grow, the channels become larger and the amount of frass is greatly increased. In order to make room for the developing larva the frass is forced outside the channel, by small openings cut through the outer bark. This is well shown in figure 118.

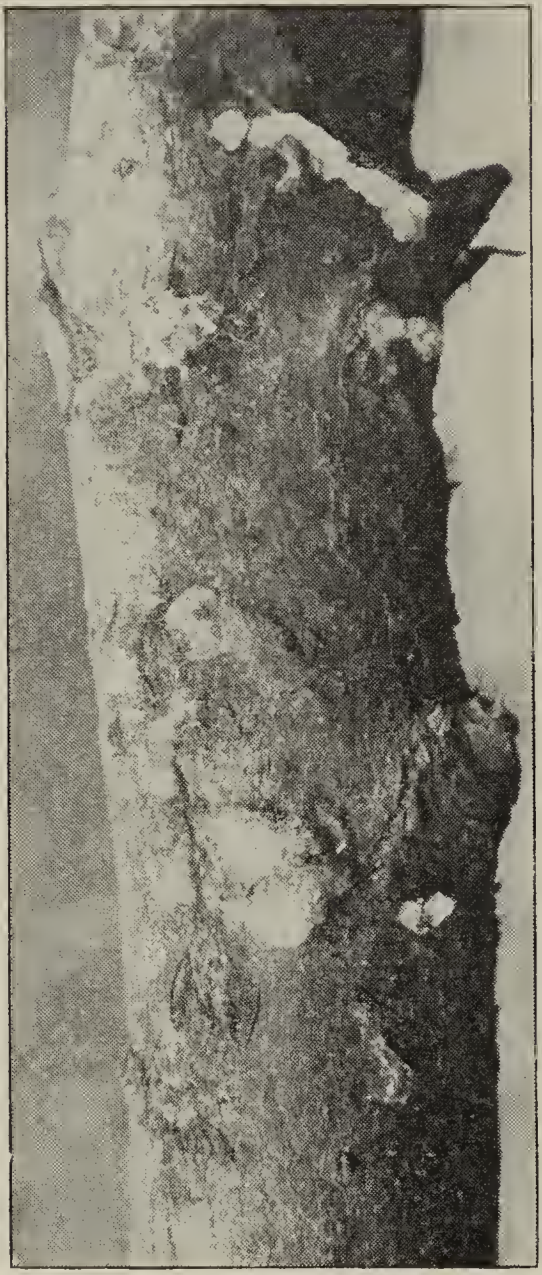

Fig. 118. FRASS FORCED OUT THROUGH SMALL OPENINGS MADE IN THE BARK BY YOUNG LARVÆ

The larvæ become nearly full-grown before they leave the cambium layer. They then burrow at an angle upward into the hard wood of the tree. The beginning of this burrow is easily recognized, as the character and quantity of the frass suddenly changes. It becomes white and much larger in quantity, and consists of small particles of the wood cut off by the mandibles of the larvæ (fig. 119). In New York the formation of the pupal channel begins about June 1. By the middle of June the majority of the larvæ have begun their pupal burrows. At this time, as one looks down the rows of poplars in the nursery the white, sawdust-like frass can be seen distinctly on the infested trees and on the ground beneath them.

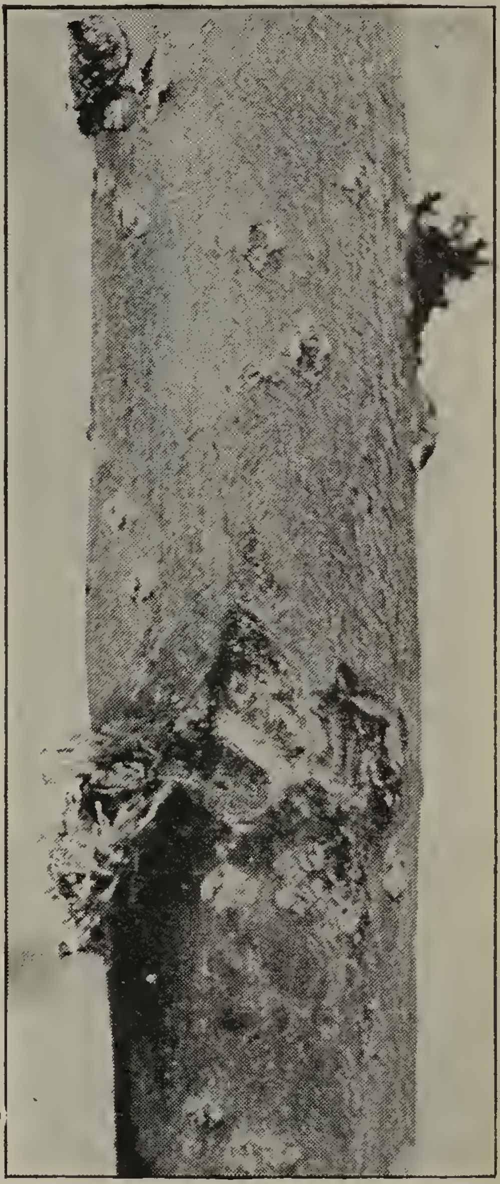

Fig. 119. CHARACTER OF THE FRASS WHEN LARVA BEGINS TO BORE INTO HEARTWOOD TO FORM PUPAL CHAMBER

In the formation of the pupal chamber the larva bores upward and into the heart of the small nursery trees. This burrow varies from slightly over an inch to several inches in length. From three to four weeks are required for its completion. When ready for pupation the burrow is solidly packed with frass, the pupal chamber being formed at the upper end (figs. 120 and 121). The larva then places itself head downward in preparation for pupation.

The mature larva (fig. 122) is a thick, legless grub, resembling that of the June beetle. It measures from 12 to 13 millimeters in length, with a maximum width of 4 millimeters. It is white or yellowish white in color, with a reddish brown head. The heavily chitinized mouth parts are black. There are no outstanding markings that distinguish this grub from many other wood-boring larvæ, and the surest way of identification is by its habits.

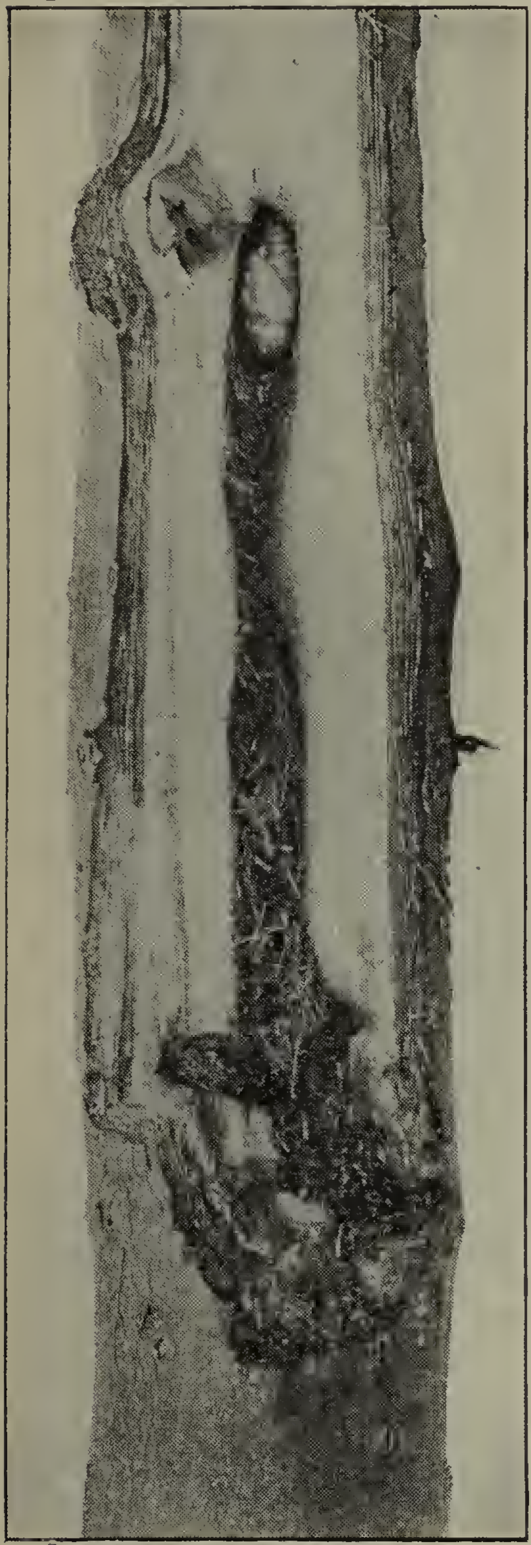

Fig. 120. pupa in situ

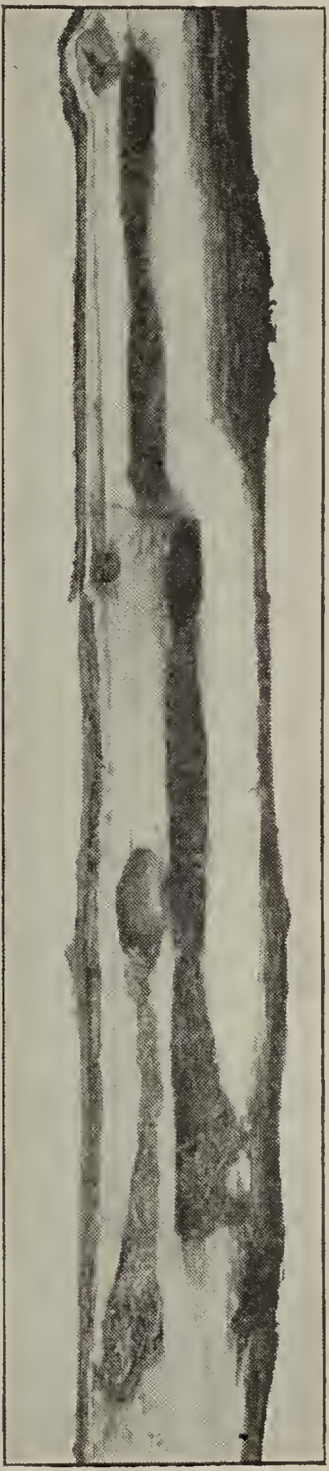

Fig. 121. three pupal chambers formed in a two-year-old carolina poplar

The pupa

Pupation begins in the last few days of June and continues throughout July. The pupal period varies from ten to eighteen days, depending largely on weather conditions. Pupæ formed early in July require only ten days, while those of late July require as long as eighteen days, to transform into adults. From two to three days are required for the adult to become fully colored and hardened. Those maturing early in the season usually remain in the pupal cells for two or three weeks before emerging. A general emergence of the adults occurs during the latter part of July. The beetle, when ready to leave, simply cuts its way out through the frass that had been packed in the burrow by the larva before pupation.

The pupa (fig. 123) measures 9 millimeters in length. It varies from almost white to yellowish in color, the brown spiracles showing distinctly. Scattered over the dorsal surface are many small spines. Some of them stand out prominently on the pronotum. The tip of the abdomen is armed with a pair of strong, incurving, brown, chitinized hooks.

Observations of European workers

The life history of the insect as outlined in the preceding paragraphs differs very markedly from that given by European workers, all of whom record the beetles as hibernating and state that mating and oviposition takes place during the spring months.

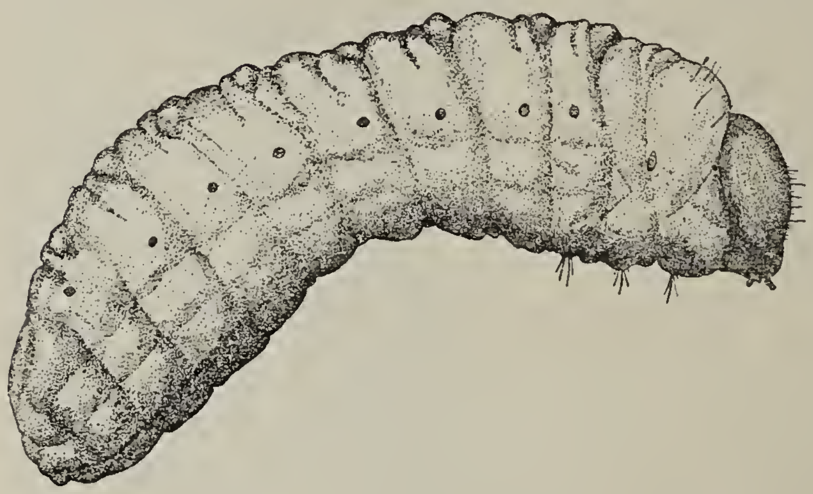

FIG. 122. THE MATURE LARVA

The latest worker, Scheidter (1913), states that the beetles emerge from hibernation about the first of May, and that in a short time mating takes place and egg laying continues throughout the summer. According to his observations, these eggs do not hatch until the following spring, so that each year both eggs and beetles of different generations hibernate. He concludes that with this insect there is a complete generation every two years: beetles emerging in 1910 hibernated, and laid eggs in 1911; these eggs hibernated, and hatched in the spring of 1912, the beetles reaching maturity in late July and August; these beetles in their turn mated and oviposited in the following spring.

Munro (1914) finds that in northern Scotland there is a complete generation every year, the beetles hibernating and ovipositing during the spring months.

Caesar (1916) finds that in Ontario considerable numbers of the beetles appear in the early spring months, but he does not know whether these have hibernated as beetles or as larvæ or pupæ. He also failed to determine whether they lay eggs during the spring months.

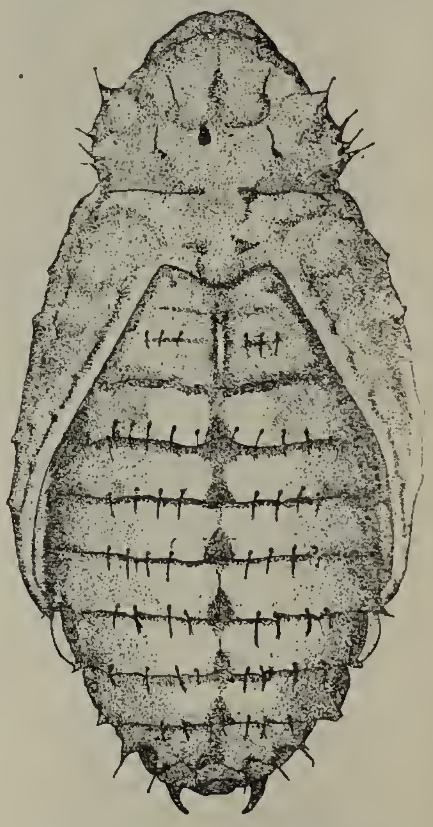

FIG. 123. THE PUPA

It would thus seem that the life history and habits of this insect are complex and vary greatly.

CONTROL MEASURES

When the writer began work on the poplar and willow borer, no efficient control measures had been devised. The general recommendations had been the cutting-out and destruction of infested trees. Schoene (1907 a) states that the use of arsenicals during July and August will kill the majority of the beetles and reduce infestation in nurseries. In practice it has been found that paris green and lead arsenate, even when used in large quantities, have no effect in reducing the annual loss. At the time when the writer began to look into this problem, in 1913, several large nurseries in New York State had about decided to stop raising carolina poplars, although there was a steady demand for this stock.

Early observations led the writer to the conclusion that the insect could be destroyed by some contact spray applied to the trunks of the trees in autumn, after the leaves had fallen, or in spring before the young larvæ had begun actively feeding. This seemed very reasonable, owing to the fairly exposed condition of the young larvæ in their burrows. It seemed that some oil emulsions would penetrate the outer bark or be absorbed through the very small quantity of frass at the entrance to the burrows, and would destroy the insects. Consequently, varying strengths of miscible oils and kerosene emulsion, applied both in the fall and in the spring, were experimented with. In order to secure a strong penetrating fluid, it was felt that carbolineum avenarius should be given a thorough trial. Very little is known about the constituents of this preparation, and furthermore very little is known of its effects on actively growing or on dormant trees.

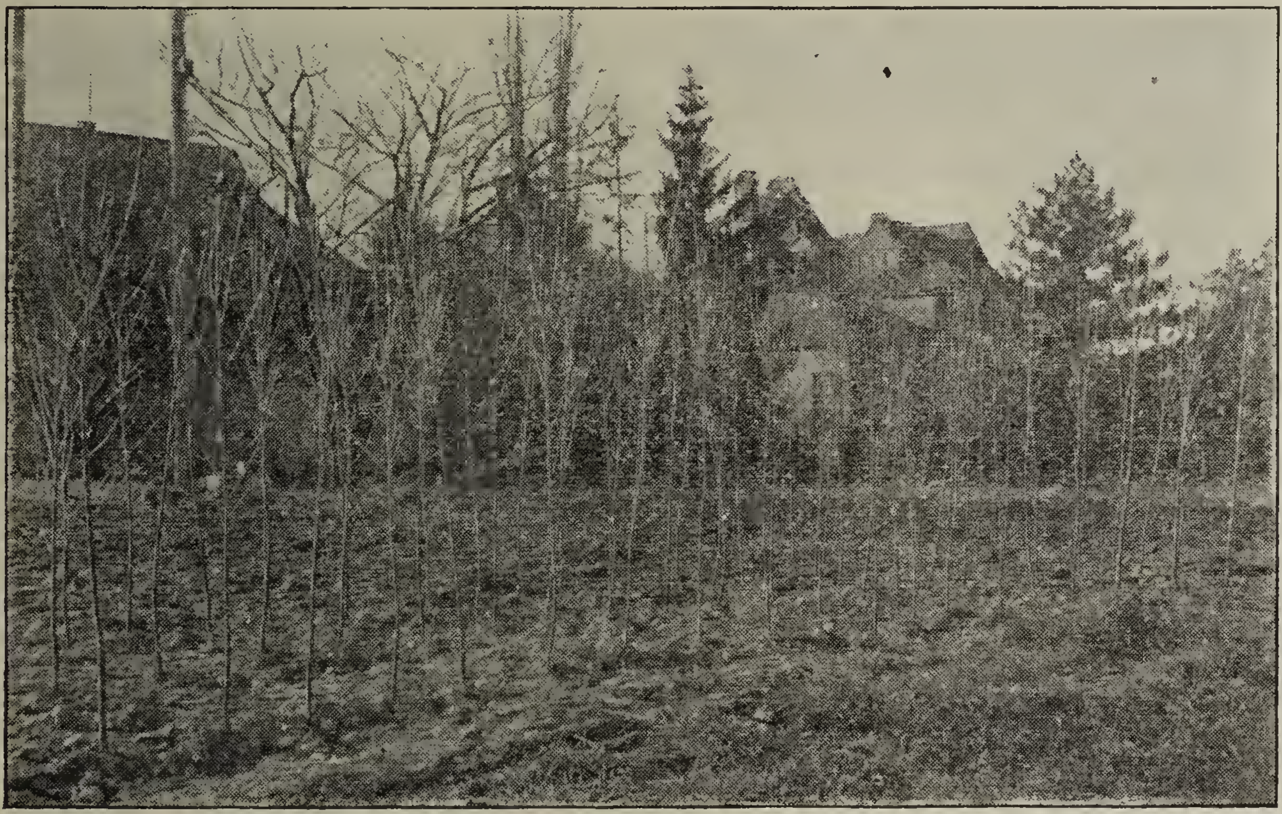

FIG. 124. AN EXPERIMENTAL PLOT OF CAROLINA POPLARS

Experiments in 1913–14

In the fall of 1913, seventy-six badly infested two-year-old poplar trees were planted near the insectary at Cornell University (fig. 124). On December 1, 1913, a part of this block was treated with scalecide at varying strengths, and a few trees were treated with carbolineum and its emulsion,[1] as indicated in table 1. This experiment was closely watched the following spring, but no injury to the trees could be noted except that the carbolineum-treated trees did not seem so vigorous as the others. However, they grew, and in 1916 they were large, healthy trees. Examination and careful count of the burrows in all the trees was made on June 17, 1914. The infestation is shown in table 1:

TABLE 1. RESULTS OF EXPERIMENTS OF 1913–14

Treatment	When applied	Number of trees treated	Date of examination	Number of trees infested	Average number of larvæ per tree	Number of trees not infested	Per cent of trees infested
Scalecide 1–5*.....	December 1, 1913	10	June 17, 1914	3	2.6	7	30
Scalecide 1–8......	December 1, 1913	10	June 17, 1914	4	1.25	6	40
Scalecide 1–10.....	December 1, 1913	10	June 17, 1914	7	2.3	3	70
Scalecide 1–12.....	December 1, 1913	10	June 17, 1914	8	1.9	2	80
Scalecide 1–15.....	December 1, 1913	10	June 17, 1914	5	2	5	50
Carbolineum 1–1 . .	December 1, 1913	2	June 17, 1914	0	......	2	0
Carbolineum emulsion 1–2........	December 1, 1913	2	June 17, 1914	0	......	2	0
Check............	....	22	June 17, 1914	10	2.6	12	45

* All dilutions of scalecide are with water.

In the spring of 1914 a series of experiments was undertaken in a large nursery. Stock three years old was chosen, as it was the most readily available at the time. Badly infested trees were selected at one side of a large block which had been recently dug. Directly across the roadway was a block of young poplars. On March 31, scalecide at varying strengths, carbolineum, and carbolineum emulsion were applied to the trunks from the ground up to the young growth. The day was fair, but rain began to fall before the various treatments were completed. However, the rainfall was slight, so that it should have had no effect on the insecticidal qualities of the preparations.

The treated trees were examined carefully on May 14, 1914. The various treatments had no effect on the growth of the trees, every tree growing vigorously and there being no difference, as far as could be detected, between the checks and the trees under experimentation. In the checks the larvæ were actively at work and their abundance was indicated by the amount of sawdust exuding from the numerous burrows. All the trees treated with different strengths of scalecide showed just as high a percentage of infestation as did the checks. This preparation had no appreciable effect. In the trees treated with carbolineum, either pure or as an emulsion, not a trace of infestation could be found. After a search of several hours, one shriveled and blackened larva was discovered in its burrow. It was not desirable, however, to injure the trees too much by cutting into all suspicious egg punctures.

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[1] The carbolineum emulsion was prepared by dissolving 1 pound of sodium carbonate in 1 quart of hot water, adding 1 quart of carbolineum, and stirring the mixture vigorously.

The trees were again carefully examined on June 18, when the previous observations were confirmed. The checks and the trees treated with scalecide were nearly all badly infested, many trees having from eight to ten borers present, while a few, both of the treated trees and the checks, were apparently free from infestation. The trees treated with carbolineum and its emulsion were growing even more vigorously than were the untreated trees, and not a trace of the work of the borer in any one of the twelve treated trees could be discovered. These preparations colored the trunks of the trees deep brown, but other than that no injury could be seen.

Experiments in 1914-15

In view of the possibility that such perfect control might be due to other causes than the effect of the treatment, a larger series of experiments was planned for the fall of 1914 and the spring of 1915. The miscible oils were discarded, and kerosene emulsion, which had been recommended for the control of the locust borer (*Cyllene robiniæ*), was given a trial. In a block of over ten thousand trees, ready for digging in the fall of 1915, rows were selected at the end showing the greatest amount of the feeding work of the beetles. On December 4, 1914, groups of twenty trees each were treated respectively with pure kerosene emulsion, carbolineum emulsion, and carbolineum. Rows for checks were left between the treated rows. The material was applied directly to the trunks, up to the younger growth. On April 9, 1915, twenty-five trees were treated with pure kerosene emulsion, fifty with carbolineum emulsion, and twenty-eight with pure carbolineum. Just previous to these treatments the trees in the whole block had been pruned carefully. The material was carefully brushed over the trunks, covering all the cut surfaces of the recently removed branches.

The trees were examined on June 28. The block as a whole showed severe infestation, sawdust being present at the base of a great many trees, and this could be seen for a long distance down the nursery row. In the rows treated with carbolineum or its emulsion no sawdust could be seen and the trees were growing vigorously, the trunks showing a deep brown color but no indication of borer work (fig. 125). The kerosene emulsion had no appreciable effect, nor did it injure the trees though it was applied in large quantities.

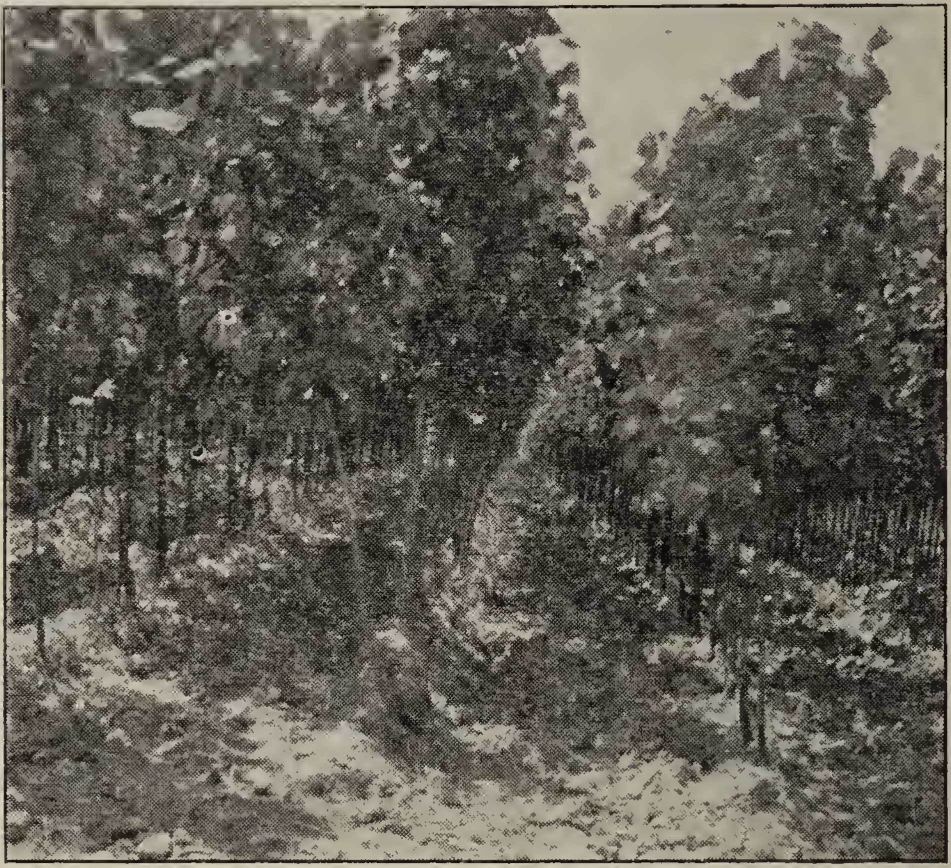

FIG. 125. TREES TREATED WITH CARBOLINEUM AND ITS EMULSION, SHOWING DARKENED TRUNKS. CHECK ROW IN CENTER

The treatments applied and the results obtained are shown in table 2. Kerosene emulsion applied pure in December seems to have had some effect, but one cannot safely draw conclusions from the result shown. The infestation of 30 per cent is high, though the average number of larvæ per tree is at a minimum. The carbolineum applied either pure or in emulsion gave almost absolute control. This seems to the writer to be a very simple and effective means of control under nursery conditions.

TABLE 2. RESULTS OF EXPERIMENTS OF 1914–15

Treatment	When applied	Number of trees treated	Date of examination	Number of trees infested	Average number of larvæ per tree	Number of trees not infested	Per cent of trees infested
Kerosene emulsion, pure	December 4, 1914	20	June 28, 1915	6	1	14	30
Kerosene emulsion, pure	April 9, 1915	25	June 28, 1915	16	2.25	9	64
Carbolineum emulsion	December 4, 1914	20	June 28, 1915	0	......	20	0
Carbolineum emulsion	April 9, 1915	50	June 28, 1915	0	......	50	*0
Carbolineum	December 4, 1914	20	June 28, 1915	0	......	20	0
Carbolineum	April 9, 1915	28	June 28, 1915	0	......	28	0
Check	....	116	June 28, 1915	56	2.4	60	48

* One half-grown larva was found in July, in an area evidently not thoroughly treated.

Experiments in 1915–16

The success of the preliminary experiments led to the trial of the carbolineum treatment on a commercial scale. In the fall of 1915 arrangements were made to treat two entire blocks of poplar trees in each of two large nurseries. This was made possible by the courtesy of the owners, who provided all the material, help, and necessary equipment, the writer taking charge of the work. Each block contained approximately fourteen thousand trees. Owing to the excessive snowfall during the winter of 1915–16 it was not possible to apply the carbolineum as early as was intended. The application was further delayed somewhat in order that the trees should be pruned.

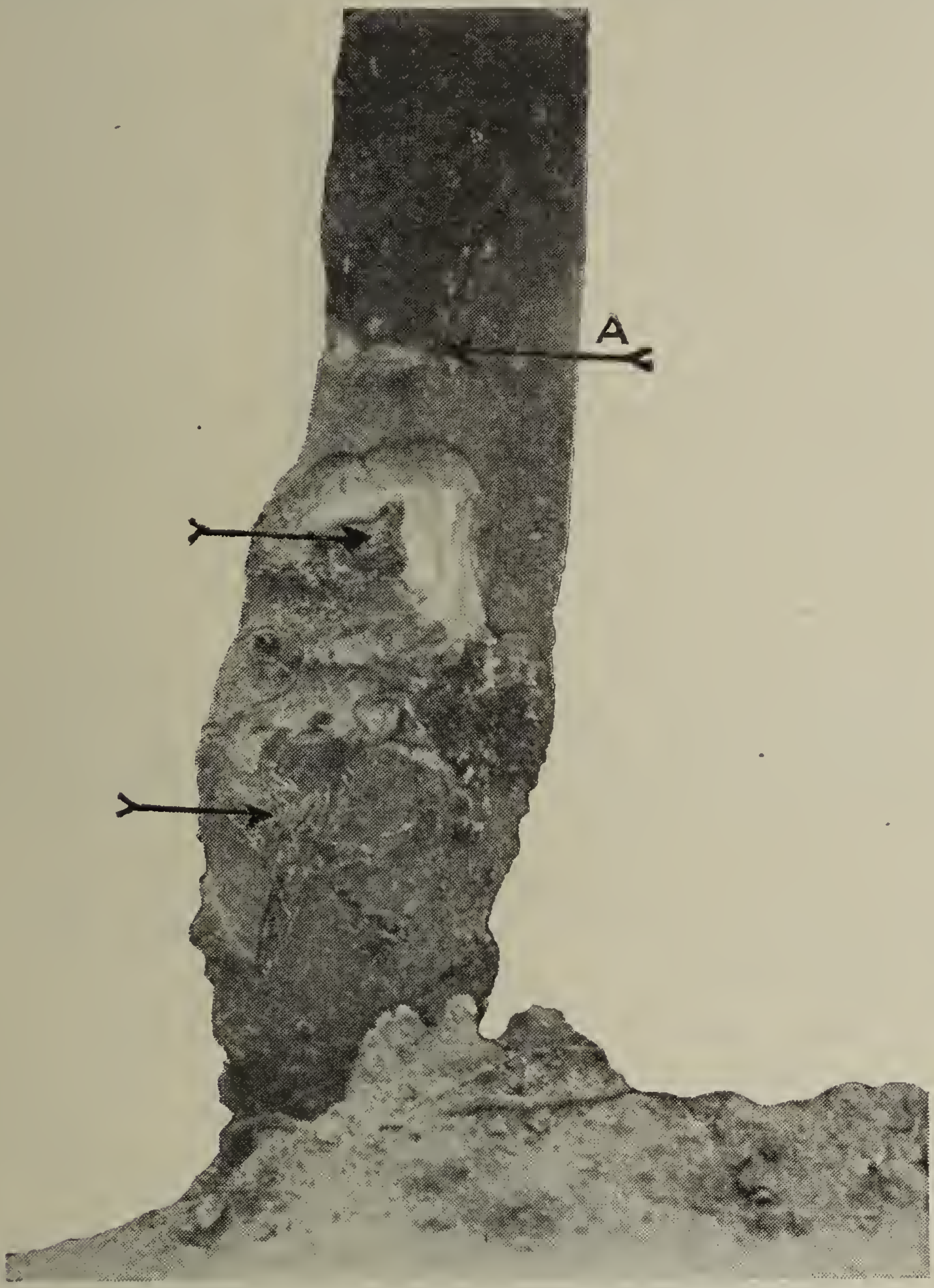

FIG. 126. INFESTATIONS BELOW LINE OF CARBOLINEUM TREATMENT

End of treatment shown by arrow A

On April 8, 1916, twenty-one rows in one block were treated. As the day was cold, threatening snow and sleet, the work was discontinued. During the following day over three inches of snow fell, and the remainder of the block was not treated until April 13. In the meantime the borers had begun feeding; in fact they had been active since about the early days of April. The results of the treatments in this block are shown in table 3.

It is seen from table 3 that practically absolute control was obtained with the carbolineum treatment. Unfortunately for the experiment, the entire check row did not show a high percentage of infestation, but it is sufficient to indicate that the treatment was effective.

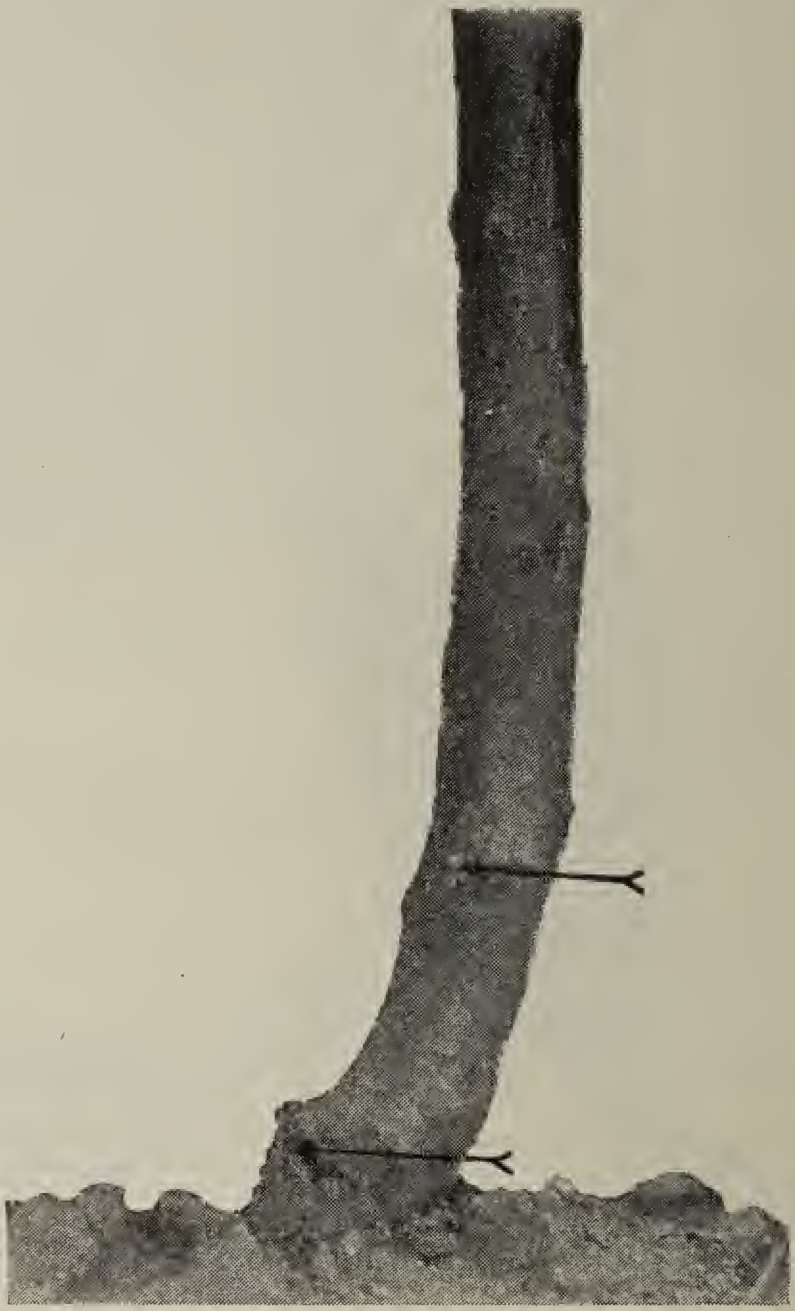

FIG. 127. TWO INFESTATIONS ALONG EDGE OF TREATMENT

In addition to the carbolineum, a high-grade creosote was tried in a limited way. The creosote also gave perfect control, and this promises well, for the row treated stood directly next to the check row.

The carbolineum gave the bark of the trees a deep brown color but it in no way affected their vigor. This brownish coloration gradually becomes reduced during the summer, but treated trees can be recognized easily at least three years after the treatment.

Another point that should be brought out here is that the four trees treated with carbolineum in the experimental plot in 1913–14 were not attacked during the summers of 1914 and 1915, and only a single larva was found in them during 1916. This would indicate that carbolineum-treated trees are not readily selected by the females for oviposition, provided untreated trees are available. This point will be further investigated by the writer.

TABLE 3. RESULTS OF EXPERIMENTS OF 1915–16

Treatment	When applied	Number of trees treated	Date of examination	Number of trees infested	Average number of larvæ per tree	Number of trees not infested	Per cent of trees infested
Carbolineum..........	April 8, 1916	5,000±	June 22, 1916	0	0	*1,161	0
	April 13, 1916	9,000±	July 20, 1916	*1	1	1,160	0
Creosote..............	April 8, 1916	136	June 22, 1916	0	0	136	0
			July 20, 1916	0	0	136	0
Check.................	....	313	June 22, 1916	9	2	304	2.9
			July 20, 1916	11	2	302	3.5

* In determining the infestation of the treated trees, not all the 14,000 trees were examined. Rows were selected in different parts of the block and every tree was examined carefully. In this way 1161 trees were closely scrutinized and not a sign of borer work could be found. The figures in the table are based on the result of this examination. In the second examination a single larva was found at work on one of the treated trees, but as this was the rare exception the fact has been ignored in the percentage column.

TABLE 4. RESULTS OF EXPERIMENTS OF 1915–16

Treatment	When applied	Number of trees treated	Date of examination	Number of trees infested	Average number of larvæ per tree	Number of trees not infested	Per cent of trees infested
Carbolineum....	April 12 and 13, 1916	14,000	June 23, 1916	20	1.4	*1,540	1.28
			July 20, 1916	20	1.4	*1,540	1.28
Check..........	....	84	June 23, 1916	8	·1	76	9.52
			July 20, 1916	8	1	76	9.52
Check (treated in June)........	....	555	June 23, 1916	19	1.2	536	3.42
			July 20, 1916	19	1.2	536	3.42

* Only 1560 trees were examined, but these were selected rows and the percentage of infestation is fairly accurate.

The results of the treatment of the second block of about an equal number of trees are shown in table 4. In this block the results were extremely interesting, showing most conclusively the effectiveness of the carbolineum treatment. The writer visited this nursery and showed the owner the method of treatment but did not further supervise the work. In treating the trees on the following day the workmen failed in many cases to cover the base of the trees with the material, and also failed to apply it sufficiently high on the trunk. As a result all the infestations, amounting to nearly 1.3 per cent, occurred either at the base or above the highest point of treatment. This is well shown in figures 126, 127, and 128.

Another interesting point in connection with this block is in regard to the check row. This row, running through the center of the block, contained 639 trees. When the owner saw the excellent results in the treated trees, he asked himself why he should not save most of the trees in the check row. Therefore on June 3, 4, or 5 — he did not know the exact date — he treated 555 of these trees, leaving some at either end as a true check. The treatment, even at this late date, had a marked effect, as shown by the percentage of infestation found on June 23. During the first week in June all the larvæ were still at work in the cambium layer, and wherever sufficient material was applied most of the larvæ were killed. The trees then readily outgrew the injury. The carbolineum had no apparent effect in retarding growth.

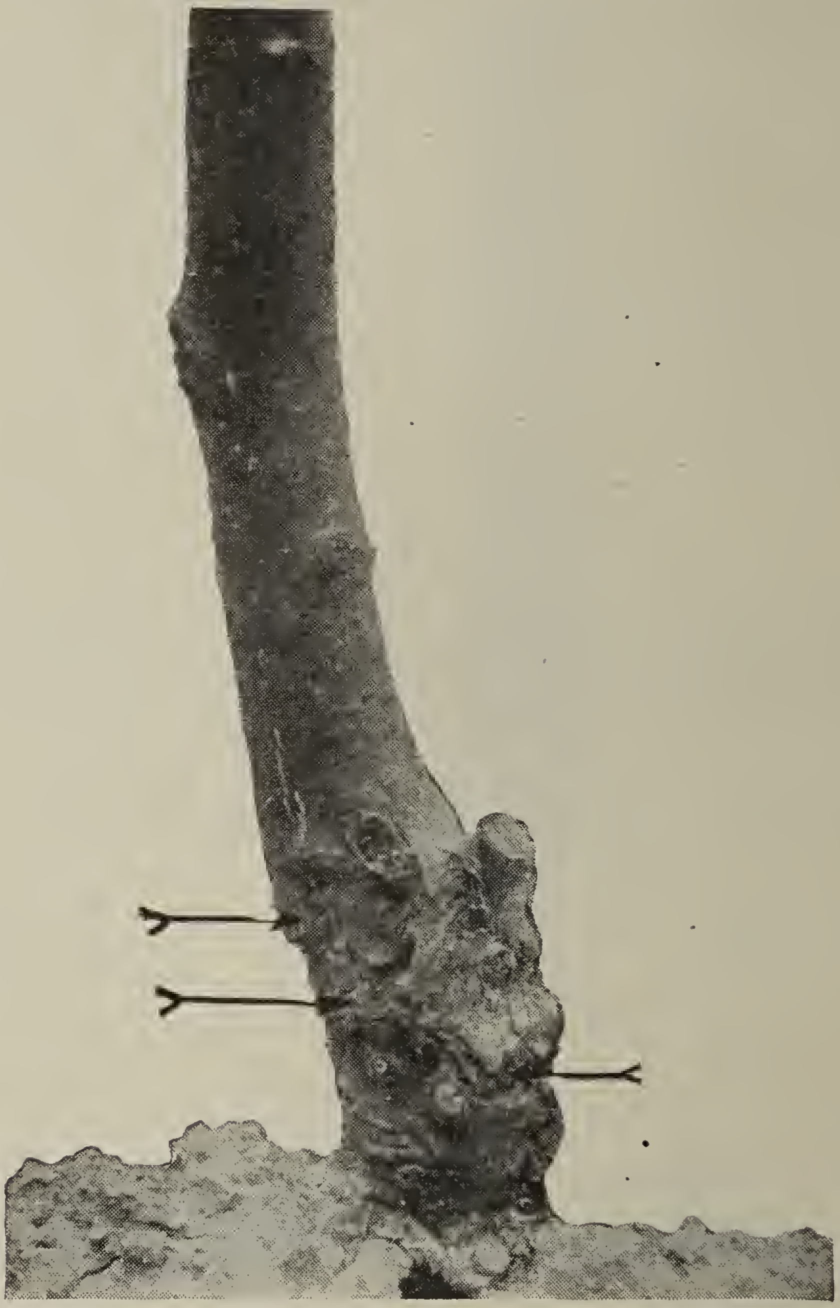

FIG. 128. TREE SEVERELY INJURED AT BASE, DUE TO LACK OF TREATMENT THERE

Method of application of carbolineum

After many trials it was found that the simplest method of application of carbolineum was by the use of cotton waste. Carbolineum is non-injurious to the hands, and each workman carried a small quantity of the material in a dipper or a tin can. The cotton waste was dipped into the material and then rubbed carefully up and down the trunk of the tree. It is usually not necessary to go higher than four or five feet, but great care should be exercised to see that the base of the tree is well treated and all parts of the trunk are well covered. At the same time the material should not be allowed to run down to the roots. After the trees are pruned workmen can apply the material at a very rapid rate. It is preferable to make the application on a warm day, as under this condition the carbolineum is thinner and may be more easily applied.

Cost of treatment

It was at first thought that the cost of the treatment might prevent its use under nursery conditions, inasmuch as poplars are not very high-priced stock. In one nursery a careful account of the entire cost of treatment was kept. This was as follows:

Labor, treating 14,000 trees	$18.50
Carbolineum, 7 gallons at 90 cents	6.30
Total cost	$24.80
Total cost per tree	$0.00177

It is thus seen that the cost per tree is extremely small, not exceeding two-tenths of a cent — a practically negligible charge.

SUMMARY

The poplar and willow borer is a European pest recently introduced into America and at present widely distributed in the northeastern United States. It is proving a serious pest not only in nurseries but also wherever willows or poplars are grown.

A very effective means for control of the insect is the use of carbolineum avenarius. In nurseries this should be applied by hand during the latter part of March or the first week in April. The work can be done most advantageously just after the trees are pruned.

In setting out poplar trees they should be treated with carbolineum in order to insure the destruction of all larvæ present. This can be done either in the fall or in the spring while the trees are dormant.

The item of cost has been shown to be extremely small, not exceeding two-tenths of a cent per tree under nursery conditions.

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CLARIFICATION OF MILK

T. J. McINERNEY

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CLARIFICATION OF MILK

T. J. McInerney

The number of bacteria found in milk indicates to a certain extent the quality of the milk as to cleanness. Under ordinary conditions the main sources of milk contamination are dust and dirt from the body of the cow, udder tissue, dust in the air of the stable, lack of cleanliness on the part of the milker, and poorly washed, unsterilized utensils. From any of these sources insoluble dirt may enter the milk, rendering it more or less objectionable for use and especially for drinking purposes.

Since it is almost impossible to prevent absolutely the falling of some dirt into the milk, many investigators have been trying to devise some means by which such dirt may be removed without causing any change in the milk itself. When the cream separator was first placed on the market, it was noticed that much of the insoluble dirt present in the milk before separation was found in the separator bowl in the form of slime after the cream and the skimmilk had been separated. This form of clarification did not prove satisfactory, however, because the milk could not be reconstituted by the mixing of the skimmilk and the cream. It is a well-known fact that cream and skimmilk cannot be satisfactorily remixed after they have been separated by centrifugal action.

HISTORICAL REVIEW OF CLARIFICATION STUDIES

When the separator was first used as a clarifier it was noticed that much slime and dirt was removed, and this led to the theory that the germ content of milk might be reduced by clarification. Studies were made by a number of investigators on the effect of centrifugal separation on germ content.

Moore (1896)[1] found that in samples of milk inoculated with pathogenic bacteria and then passed thru a separator, the greatest number of bacteria was found in the slime and the least in the skimmilk. There were enough bacteria present in the skimmilk, however, to kill animals inoculated with or fed on this milk. Moore states further that some species of bacteria are more thoroly eradicated than others. He concludes that separation is not efficient in removing bacteria from milk, since there are practically as many bacteria in the cream and the skimmilk after separation as in the original milk, plus a large number in the sediment.

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[1] Dates in parenthesis refer to bibliography, page 504.

Eckles and Barnes (1901) summarize their work as follows:

1. The centrifugal separator removes practically all the solid impurities from milk.
2. From 37 to 56 per cent of the total number of germs were thrown out with the slime.
3. An average of 29 per cent of the total number of germs went into the skim milk, 24 per cent into the cream and about 47 per cent into the slime.
4. The keeping qualities of the milk are improved but little if any by centrifugal separation.

Dean (1903) found, in a series of experiments, that clarifying and filtering seemed to have no effect on the keeping quality of milk.

Harrison (1903) found that in twenty-four out of thirty experiments the bacteria content of cream and skimmilk remixed after separation was greater than that of the milk before separation. The number of liquefying bacteria was largely increased by separation. These results tend to show that as far as bacteria are concerned this method of purification is ineffectual.

Doane (1903) found that the purification of milk by the use of separators as practiced by two city dairies failed to give satisfaction to consumers, the main objection being that the milk so treated became sour sooner than did untreated milk.

Diffloth (1905) tried to purify milk with filters and separators. He found that milk filtered thru animal charcoal that had been washed thoroly in water was turned black, illustrating a difficulty in purifying milk by filtration as compared with purifying water.

Severin (1905) tried three methods of centrifuging, making bacteria counts immediately before and after the treatment. The methods were as follows: (1) ordinary centrifugal separation; (2) protecting centrifuge with sterilized cotton in order to prevent entrance of bacteria from the air; and (3) shaking the milk in closed bottles before and after centrifuging. The interval between the taking of samples was about fifteen minutes. The number of colonies developing on agar and on gelatin was increased by all three methods. Contamination from air during separation was thus excluded as a source of the increase of bacteria. Severin believes the reason for this increase is that the natural process of vegetative division is hastened by the mechanical action, so that bacteria about to become separated are torn apart sooner than would ordinarily be the case.

Anderson (1909) found that centrifugally raised cream contained more bacteria per cubic centimeter than cream raised by gravity.

Ernst (1914) states that altho a great number of bacteria are removed by clarification, the bacteria count thru plating of the centrifuged milk discloses a considerably larger number of colonies than were found in the milk prior to centrifugalization, altho the short time of the centrifuging process does not permit of an actual increase of bacteria. This may be explained, according to Ernst, by the fact that clumps of pus and fatty leucocytes which have " embodied " bacteria are distributed thru centrifugalization. Therefore, in spite of the removal of considerable numbers of bacteria, there is an apparent increase.

According to Hammer (1916), Fleischmann doubts whether the centrifuge has much value as a means of purification. In direct contradiction to this are the opinions of Grotenfelt and Hueppe, who believe the centrifugal separator is of value as a means of purification because it throws out a large proportion of the injurious germs in milk (Hammer, 1916:20).

Besides the use of centrifugal separation for purifying milk, various methods of straining and filtering thru absorbent cotton, sand, quartz, or substances of similar character, have been tried. By these methods the coarser dirt and objectionable matter is removed from the milk, but they are only half efficient at best. In some respects they are really more harmful than beneficial, in that they are open to the very serious objection that all the milk passing thru the filter may be permeated and contaminated by anything that may be caught in the filtering material.

THE CLARIFIER

The demand arose for a form of machine that would remove the insoluble dirt from milk without producing any noticeable changes in the milk. Such a machine, which removes the insoluble dirt by means of centrifugal force, has been placed on the market and is known as a clarifier.

The purpose of this bulletin is to determine the advantages and the disadvantages of the clarifier in commercial work. The points considered are (1) the effect of clarification on the germ content of milk, (2) the chemical effects of clarification, and (3) the physical effects of clarification.

METHOD OF PROCEDURE

In these experiments the parts of the clarifier were thoroly washed and sterilized before using. After the machine was assembled, sterilized water was run thru it and plated, in order to determine whether or not sterilization was complete. The bowl of the clarifier was then protected with cheesecloth until the milk was ready to be passed thru the machine. A sterilized can was used to receive the milk after it had passed thru the clarifier. Samples of milk to be examined were taken immediately before and after clarifying.

The germ content was determined by the plate method. All samples were plated in lactose agar and held at a temperature of 37° C. for three days. The plates were then counted and the total number of bacteria was determined. All samples were again plated, after being held for twenty-four hours at a temperature of 10° C., in order to compare the development of bacteria in the clarified and the unclarified milk.

The total solids were determined by the chemical method, and the fat content was determined by the Babcock method. The acidity was determined by titrating 18 grams of the sample with a one-tenth normal alkali solution. The amount of insoluble dirt was determined by filtering equal quantities of clarified and unclarified milk thru absorbent cotton and comparing the amount of sediment obtained in each case. The amount of cream rising was determined by filling graduated, straight-sided cylinders, of 100 cubic centimeters capacity, with the samples, allowing them to stand for twenty-four hours, and then reading and recording the number of cubic centimeters of cream raised in each sample. The keeping quality was determined by holding samples of clarified and of unclarified milk at definite temperatures and noting the time required for the milk to curdle.

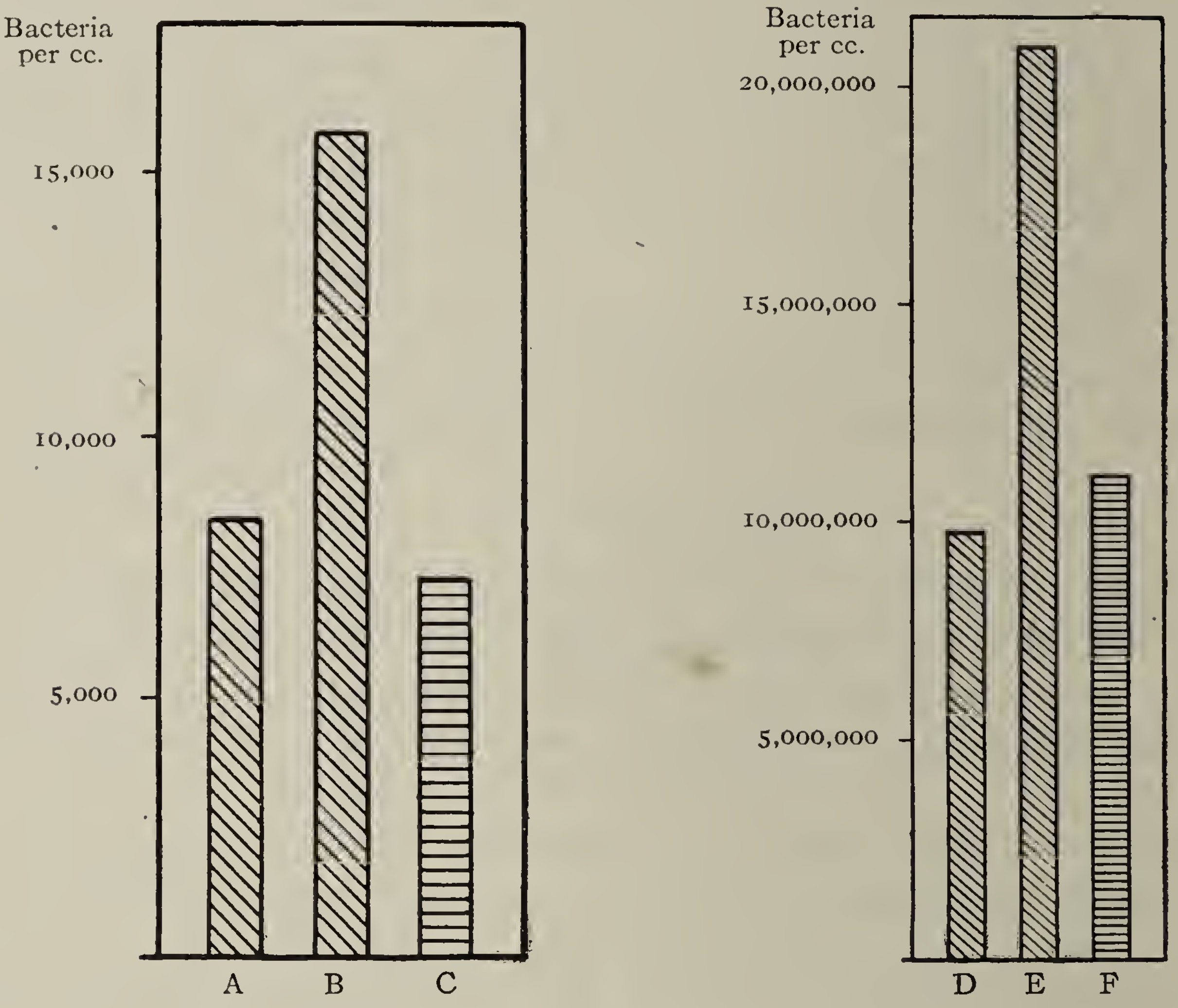

FIG. 129. EFFECT OF CLARIFICATION ON BACTERIA CONTENT OF MILK

A, Bacteria per cubic centimeter in unclarified fresh milk; B, bacteria in the same milk after clarification; C, increase due to clarification
D, Bacteria per cubic centimeter in unclarified old milk; E, bacteria in the same milk after clarification; F, increase due to clarification

RESULTS

Effect of clarification on the bacteria content of milk

The effect of clarification on the bacteria content of fresh milk is shown in table 1 and in figure 129, A-C. The milk used in these experiments was from the university farm and was produced under sanitary conditions. In nearly all cases morning milk was used, the object being to provide milk with as low a germ content as possible; night milk would have contained a greater number of bacteria by morning, when the tests were made.

TABLE 1. Effect of Clarification on the Bacteria Content of Fresh Milk

Experiment	Bacteria per cubic centimeter		Increase	
	In unclarified milk	In clarified milk	Per cubic centimeter	Per cent
1	700	1,600	900	128.57
2	2,300	2,400	100	43.48
3	641	1,825	1,184	184.71
4	1,250	2,483	1,233	98.64
5	563	2,900	2,337	415.10
6	1,400	1,475	75	5.36
7	525	1,100	575	109.52
8	6,000	9,000	3,000	50.00
9	10,000	30,000	20,000	200.00
10	1,100	1,400	300	27.27
11	5,000	10,000	5,000	100.00
12	4,000	4,000	0	....
13	4,500	18,000	13,500	300.00
14	3,600	5,000	1,400	38.89
15	2,100	2,600	500	23.81
16	3,650	5,550	1,900	52.05
17	7,000	20,000	13,000	185.71
18	5,480	12,125	6,645	121.26
19	10,000	13,000	3,000	30.00
20	11,320	13,600	2,280	20.14
21	4,280	8,000	3,720	86.91
22	4,600	4,250	−350	....
23	1,600	4,100	2,500	156.25
24	15,000	22,000	7,000	46.67
25	53,000	71,500	18,500	34.90
26	60,000	156,000	96,000	160.00
27	5,675	5,775	100	1.76
28	10,200	11,000	800	7.84
Average	8,410	15,739	7,329	87.15

The initial count was less than 10,000 bacteria per cubic centimeter in twenty-one of the samples, while after clarification only seventeen showed a count less than 10,000 bacteria per cubic centimeter. In one sample the number of bacteria remained the same after clarification and in one there was a decrease. The percentage of increase ranged from 1.76 to 415.10, the average being 87.15. According to the figures, if a milk with a very low bacteria count is clarified, even tho the clarified milk shows an increase of 100 per cent in the bacteria count this count in the end would not necessarily mean a high-count milk.

These experiments were performed at various times thru a period of two years. Some of the work was done in the winter months and some in the summer months. There was no noticeable difference in the results of experiments performed at various times of the year.

TABLE 2. EFFECT OF CLARIFICATION ON THE BACTERIA CONTENT OF OLD AND DIRTY MILK

Experiment	Bacteria per cubic centimeter		Increase	
	In unclarified milk	In clarified milk	Per cubic centimeter	Per cent
1	830,000	13,900,000	13,070,000	1,574.70
2	40,000	110,000	70,000	175.00
3	494,000	6,400,000	5,906,000	1,195.55
4	133,500	197,500	64,000	47.94
5	15,000,000	30,000,000	15,000,000	100.00
6	37,800,000	40,000,000	2,200,000	5.82
7	1,500,000	3,200,000	1,700,000	113.33
8	370,000	643,000	273,000	73.78
9	600,000	1,300,000	700,000	116.67
10	55,000	175,000	120,000	218.18
11	19,000,000	160,000,000	141,000,000	742.10
12	248,000	425,000	177,000	71.37
13	558,750	1,863,300	1,304,550	233.48
14	190,000	237,000	47,000	24.74
15	83,400,000	91,030,000	7,630,000	9.15
16	1,590,000	1,831,000	241,000	15.16
17	4,420,000	5,700,000	1,280,000	28.96
Average	9,778,191	21,000,694	11,222,503	114.77

The effect of clarification on the germ content of old and dirty milk is shown in table 2 and in figure 129, D-F. The milk was obtained from sources not under city inspection, and the conditions under which it was produced and handled were not considered sanitary. Some milk producers carelessly allow insoluble dirt to fall into the milk, thinking that it can be removed by straining or by clarification. It was to test this point that studies were made on the effect of clarification on the germ content of dirty milk.

As shown in figure 133 (page 501), clarification removes a large proportion of the insoluble dirt. According to the results shown in table 2, however, the bacteria count is increased rather than decreased. In all the seventeen samples there was an increase, ranging from 47,000 to 141,000,000 bacteria per cubic centimeter, the average of the percentage of increase being 114.77.

Even with the same percentage of increase in milk with a high initial count as in milk with a low initial count, the fact that the former has a high count at the beginning would probably put it in a lower grade after clarification than before. From a bacteriological standpoint, then, it would seem that old milk should not be clarified.

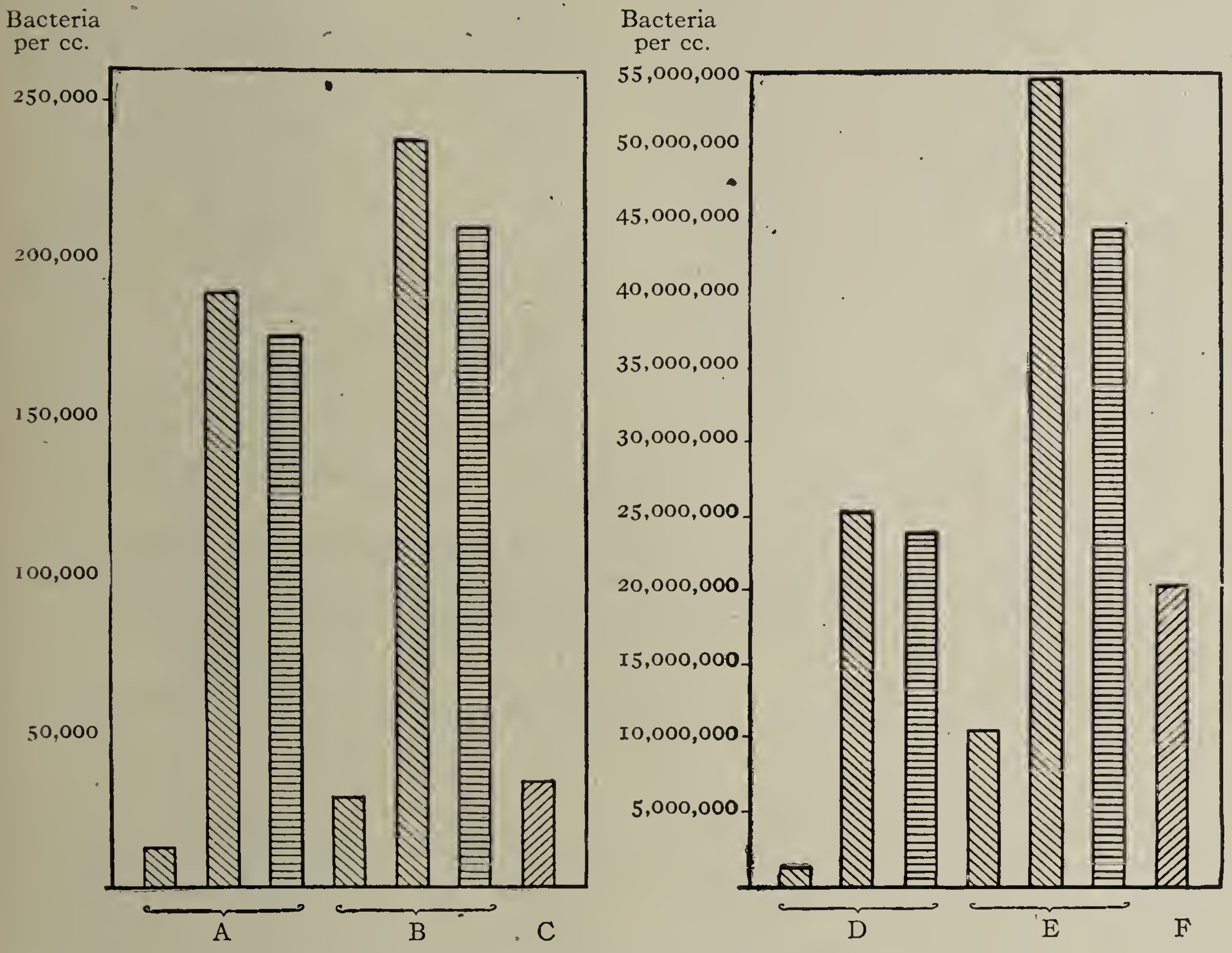

FIG. 130. RATE OF DEVELOPMENT OF BACTERIA IN UNCLARIFIED MILK AS COMPARED WITH THE SAME MILK AFTER CLARIFICATION

Showing bacteria content in milk when fresh and when old, and increase in bacteria content after twenty-four hours at 14.4° C.
A, Clean milk, unclarified; B, same milk after clarification; C, increase in clarified over unclarified milk
D, Dirty milk, unclarified; E, same milk after clarification; F, increase in clarified over unclarified milk

The development of bacteria in clarified milk was compared with that in unclarified milk. Samples of clean milk and of dirty milk, both before and after clarification, were kept at a temperature of 14.4° C. for twenty-four hours and then plated to determine the number of bacteria present. The results of this work are shown in tables 3 and 4 and in figure 130.

TABLE 3. Development of Bacteria in Clean Milk

Experiment	Bacteria per cubic centimeter in unclarified milk			
	Fresh	After 24 hours at 14.4° C.	Increase	
			Per cubic centimeter	Per cent
1	4,000	10,000	6,000	150.00
2	5,500	42,000	36,500	663.64
3	4,000	10,000	6,000	150.00
4	4,500	18,000	13,500	300.00
5	3,600	602,000	598,400	16,622.22
6	2,350	221,000	218,650	9,304.25
7	3,650	97,500	93,850	2,571.23
8	7,000	774,000	767,000	10,957.14
9	5,480	248,000	242,520	4,425.55
10	7,550	69,733	62,183	823.61
11	15,000	22,000	7,000	46.67
12	53,000	380,000	327,000	616.98
13	60,000	265,000	205,000	341.67
14	5,675	9,500	3,825	67.40
15	10,200	55,000	44,800	439.21
Average	12,767	188,249	175,482	1,374.50

TABLE 4. Development of Bacteria in Dirty Milk

Experiment	Bacteria per cubic centimeter in unclarified milk			
	Fresh	After 24 hours at 14.4° C.	Increase	
			Per cubic centimeter	Per cent
1	1,500,000	12,000,000	10,500,000	700.00
2	370,000	8,000,000	7,630,000	2,062.16
3	600,000	23,000,000	22,400,000	3,733.33
4	47,000	1,124,000	1,077,000	2,291.49
5	12,000,000	33,000,000	21,000,000	175.00
6	95,000	1,450,000	1,355,000	1,426.31
7	190,000	30,000,000	29,810,000	15,689.47
8	40,000	1,000,000	960,000	2,400.00
9	33,000	1,800,000	1,767,000	5,354.54
10	133,000	7,500,000	7,367,000	5,539.10
11	48,500	1,124,000	1,075,500	2,217.52
12	12,000,000	335,000,000	323,000,000	2,691.67
13	21,500	2,800,000	2,778,500	12,923.25
14	95,000	1,450,000	1,355,000	1,426.31
15	170,000	7,800,000	7,630,000	4,488.23
16	2,350	220,000	217,650	9,261.70
17	190,000	30,000,000	29,810,000	15,689.47
18	37,000	1,095,000	1,058,000	2,859.46
19	133,500	540,000	406,500	304.49
20	494,000	6,400,000	5,906,000	1,195.55
Average	1,409,993	25,265,150	23,855,157	1,691.86

after Being Held for Twenty-four Hours at 14.4° C.

Experiment	Bacteria per cubic centimeter in clarified milk			
	Fresh	After 24 hours at 14.4° C.	Increase	
			Per cubic centimeter	Per cent
1	8,000	30,000	22,000	275.00
2	12,000	40,000	28,000	233.33
3	4,000	20,000	16,000	400.00
4	6,000	29,000	23,000	383.33
5	5,000	785,000	780,000	15,600.00
6	3,350	175,000	171,650	5,123.88
7	5,550	279,000	273,450	4,927.03
8	16,000	805,000	789,000	4,931.25
9	12,125	433,300	421,175	3,473.61
10	7,500	464,000	456,500	6,086.67
11	26,000	27,000	1,000	3.85
12	114,000	114,000	0	....
13	181,500	295,000	113,500	62.53
14	5,775	5,900	125	2.16
15	11,000	67,006	56,006	509.14
Average	27,853	237,947	210,094	754.29

after Being Held for Twenty-four Hours at 14.4° C.

Experiment	Bacteria per cubic centimeter in clarified milk			
	Fresh	After 24 hours at 14.4° C.	Increase	
			Per cubic centimeter	Per cent
1	3,200,000	24,000,000	20,800,000	650.00
2	643,000	20,000,000	19,357,000	3,010.42
3	1,300,000	45,000,000	43,700,000	3,361.54
4	170,000	1,024,000	854,000	502.35
5	18,000,000	77,000,000	59,000,000	327.78
6	100,000	2,070,000	1,970,000	1,970.00
7	180,000	30,000,000	29,820,000	16,566.67
8	70,000	4,800,000	4,730,000	6,757.14
9	48,000	1,700,000	1,652,000	3,441.67
10	187,000	12,500,000	12,313,000	6,584.49
11	165,500	1,022,000	856,500	517.52
12	180,000,000	800,000,000	620,000,000	344.44
13	36,500	3,400,000	3,363,500	9,215.07
14	100,000	2,070,000	1,970,000	1,970.00
15	78,250	22,000,000	21,921,750	28,015.01
16	3,350	165,000	161,650	4,825.37
17	179,000	30,000,000	29,821,000	16,659.78
18	70,000	4,800,000	4,730,000	6,757.14
19	197,500	2,160,000	1,962,500	993.67
20	1,200,000	10,800,000	9,600,000	800.00
Average	10,296,405	54,725,550	44,429,145	431.50

In the case of the clean milk (table 3), it was found that in nine of the fifteen tests made there was a greater percentage of increase in bacteria content in the unclarified milk than in the clarified milk, the average percentage of increase being 1374.50 for the former and 754.29 for the latter. With the dirty milk (table 4), there was a more uniform increase in the number of bacteria per cubic centimeter in the clarified milk as compared with the unclarified milk, and the average percentage of increase was 1691.86 for the unclarified milk and 431.50 for the clarified milk.

TABLE 5. AMOUNTS OF SLIME OBTAINED FROM DIFFERENT QUANTITIES OF MILK

Experiment	Milk used (ounces)	Slime obtained (ounces)	Per cent of slime
1	89,088	5.64	0.0063
2	82,964	7.65	0.0092
3	87,680	6.98	0.0080
4	88,960	6.49	0.0073
5	89,088	6.80	0.0076
6	84,480	12.62	0.0149
7	84,480	8.25	0.0098
8	84,480	6.45	0.0076

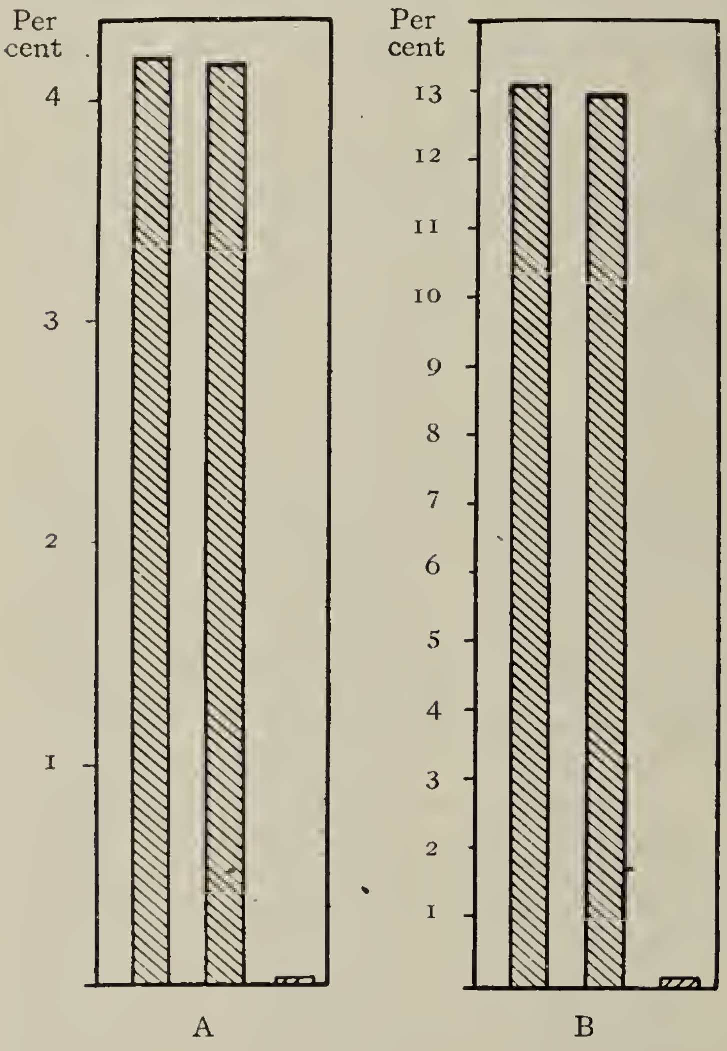

FIG. 131. PERCENTAGE OF (A) FAT AND (B) TOTAL SOLIDS IN UNCLARIFIED MILK AS COMPARED WITH THE SAME MILK AFTER CLARIFICATION

Effect of clarification on the composition of milk

The large amount of slime deposited in the clarifier bowl seemed to indicate that clarification might reduce the total solids of the milk, and possibly the fat content, and experiments were made to determine whether this was the case. The amounts of slime obtained from different quantities of milk when passed thru the clarifier are shown in table 5.

The clarifier used in these studies was a large one in a commercial plant in which several thousand pounds of milk were clarified daily. The amount of milk used was determined by weighing before passing the milk thru the clarifier. After all the milk had been passed thru, the machine was taken apart and the amount of slime deposited on the walls was carefully removed, placed in a bottle, and weighed. The percentage of slime in all cases was very small, the highest being 0.0149. This shows that even tho some of the milk solids may be removed, the percentage is so small as to be almost negligible.

The results of studies made to determine the fat content of milk before and after clarification are shown in table 6 and in figure 131, A. Tests for fat content were made in duplicate by the Babcock method. In sixteen cases out of twenty the percentage of fat in the clarified milk was exactly the same as in the unclarified milk, while in the other four cases the difference was only 0.1 per cent. This is within the limit of error of the Babcock test, and the conclusions are that clarification has no effect on the fat content of milk.

TABLE 6. EFFECT OF CLARIFICATION ON THE FAT CONTENT OF MILK

Experiment	Fat content		
	In unclarified milk (per cent)	In clarified milk (per cent)	Difference (per cent)
1	5.3	5.3	0
2	4.1	4.1	0
3	4.1	4.1	0
4	3.4	3.3	—0.1
5	3.4	3.4	0
6	4.5	4.5	0
7	4.5	4.5	0
8	4.5	4.5	0
9	5.3	5.3	0
10	4.3	4.2	—0.1
11	4.4	4.4	0
12	4.0	4.0	0
13	3.7	3.6	—0.1
14	3.5	3.5	0
15	4.7	4.8	+0.1
16	4.2	4.2	0
17	3.5	3.5	0
18	3.8	3.8	0
19	3.4	3.4	0
20	5.0	5.0	0
Average	4.18	4.17	—0.01

The results of studies on the effect of clarification on the total solids in milk are shown in table 7 and in figure 131, B. The percentage of total solids present in the samples was determined by the chemical method.

TABLE 7. EFFECT OF CLARIFICATION ON TOTAL SOLIDS IN MILK

Experiment	Total solids		
	In unclarified milk (per cent)	In clarified milk (per cent)	Difference (per cent)
1	14.81	14.77	—0.04
2	13.02	12.99	—0.03
3	13.02	13.03	+0.01
4	12.43	12.39	—0.04
5	12.43	12.41	—0.02
6	13.55	13.43	—0.12
7	13.55	13.55	0
8	13.57	13.42	—0.15
9	14.27	14.11	—0.16
10	13.13	13.07	—0.06
11	13.45	13.33	—0.12
12	13.20	13.19	—0.01
13	12.26	12.15	—0.11
14	12.20	12.16	—0.04
15	14.16	14.06	—0.10
16	13.15	13.12	—0.03
17	11.86	11.86	0
18	12.42	12.45	+0.03
19	12.02	12.09	+0.07
20	12.32	12.27	—0.05
21	12.67	12.58	—0.09
22	13.21	13.06	—0.15
23	12.83	12.88	+0.05
24	12.90	12.90	0
25	12.96	12.86	—0.10
Average	13.016	12.965	—0.051

In nearly all cases there was a slight reduction in the amount of total solids in the clarified milk as compared with the unclarified milk, the average reduction for the twenty-five samples being 0.051 per cent. This reduction may be accounted for by the amount of slime deposited in the clarifier bowl.

The development of acidity in unclarified and in clarified milk may be compared by means of table 8 and figure 132. According to these figures, there is practically no difference in the amount of acidity developed in unclarified and in clarified milk.

It was decided that a chemical analysis should be made of the slime in the clarifier bowl, in order to find out what was actually being removed from the milk. Examined under the microscope, this slime is seen to contain cow hairs, epithelium from the udder of the cow, and bacteria of many forms. In some cases the slime is red from the amount of blood in the milk.

TABLE 8. DEVELOPMENT OF ACIDITY IN UNCLARIFIED AND IN CLARIFIED MILK

Experiment	Acidity at start (per cent)	Acidity after 24 hours at 4.4° C.		Acidity after 24 hours at 21.1° C.	
		In unclarified milk (per cent)	In clarified milk (per cent)	In unclarified milk (per cent)	In clarified milk (per cent)
1	0.18	0.19	0.19	0.20	0.21
2	0.19	0.17	0.16	0.60	0.89
3	0.17	0.17	0.17	0.96	0.85
4	0.17	0.17	0.17	0.55	0.56
5	0.17	0.18	0.17	0.86	0.88
6	0.18	0.17	0.17	0.96	0.98
7	0.16	0.16	0.18	0.18	0.18
8	0.18	0.17	0.17	0.80	0.76
9	0.18	0.17	0.17	0.28	0.53
10	0.17	0.17	0.17	0.21	0.20
11	0.17	0.17	0.17	0.23	0.20
12	0.19	0.18	0.19	0.40	0.42
13	0.20	0.25	0.28	0.81	0.82
14	0.16	0.29	0.38	0.99	0.99
15	0.20	0.20	0.20	1.00	1.00
16	0.19	0.18	0.18	0.42	0.45
17	0.19	0.19	0.19	0.24	0.25
Average	0.18	0.19	0.19	0.57	0.60

Richmond and Fleischmann (Richmond, 1914) give the composition of separator slime as follows:

	Richmond	Fleischmann
Water	66.24	67.3
Fat	0.50	1.1
Casein (or analogous body)	22 (approx.)	25.9
Milk-sugar	0.5	2.1
Other organic matter	7.75	
Ash	3.01	3.6

The results of the chemical analysis of eight samples of clarifier slime, obtained from a large commercial clarifier and believed to be representative samples, are given in table 9:

TABLE 9. CHEMICAL ANALYSIS OF CLARIFIER SLIME

Experiment	Fat (per cent)	Water (per cent)	Total solids (per cent)	Ash (per cent)	Nitrogen (per cent)	Casein (per cent)
1	4.0	70.13	29.87	4.17	0.43	2.74
2	5.0	71.86	28.14	2.73	0.23	1.46
3	3.4	70.04	29.96	3.81	0.71	4.52
4	3.2	69.92	30.08	3.00	0.14	0.89
5	4.0	75.50	24.50	2.74	0.31	1.97
6	5.0	71.01	28.99	3.36	0.10	0.63
7	3.7	71.35	28.65	2.59	0.49	3.12
8	4.0	70.87	29.13	2.83	0.27	1.72
Average	4.0	71.33	28.67	3.15	0.33	2.13

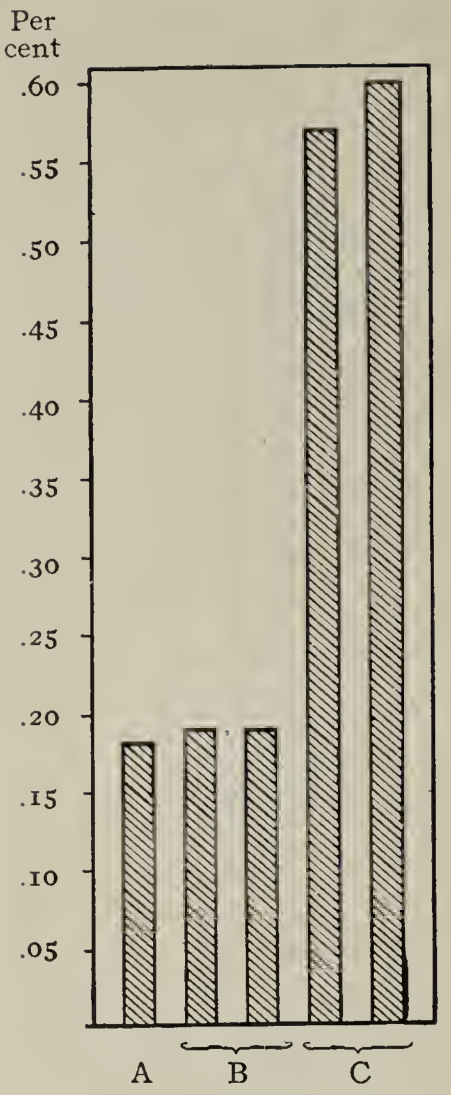

FIG. 132. DEVELOPMENT OF ACID IN UNCLARIFIED MILK AS COMPARED WITH THE SAME MILK AFTER CLARIFICATION

A, Acidity at start; B, after twenty-four hours at 4.4° C.; C, after twenty-four hours at 21.1° C.

The average percentages of the various constituents as shown in the table may seem high; but the percentage of slime resulting from clarification is so small (table 5, page 496) that, no matter how high a percentage of any constituent may be found in the slime, it is a negligible amount in consideration of the quantity of milk used.

Physical effects of clarification on milk

Keeping quality, or time of curdling.— Samples of milk taken before and after clarification were kept at different temperatures, as shown in table 10, and the time of curdling was noted. The results show practically no advantage nor disadvantage in either case.

Insoluble dirt removed.— Samples of milk taken before and after clarification were tested for sediment. A pint of the milk was passed thru a piece of absorbent cotton in a wizard sediment tester, and the dirt in the milk was caught and held by the cotton while the milk passed thru. By comparing the amounts of insoluble dirt deposited on the cotton filter the relative cleanliness of the milk before and after clarification was determined. The results obtained are illustrated in figure 133. Four samples of

TABLE 10. TIME OF CURDLING OF MILK KEPT AT DIFFERENT TEMPERATURES

Experiment	Milk kept at					
	21.1° C.		14.4° C.		8.9° C.	
	Unclarified milk soured in	Clarified milk soured in	Unclarified milk soured in	Clarified milk soured in	Unclarified milk soured in	Clarified milk soured in
1.	20 hours	20 hours	5 days	5 days	16 days	16 days
2.	20	22	6	6	16	16
3.	30	30	7	7	16	16
4.	25	20	7	7	16	16
5.	43	43	10	10	16	16
6.	32	32	10	10	16	16
7.	38	38	10	10	16	16
8.	30	30	12	12	16	16
9.	26	26	12	12	16	16
10.	26	26	12	12	16	16
Average	29 hours	28.7 hours	9.1 days	9.1 days	16 days	16 days

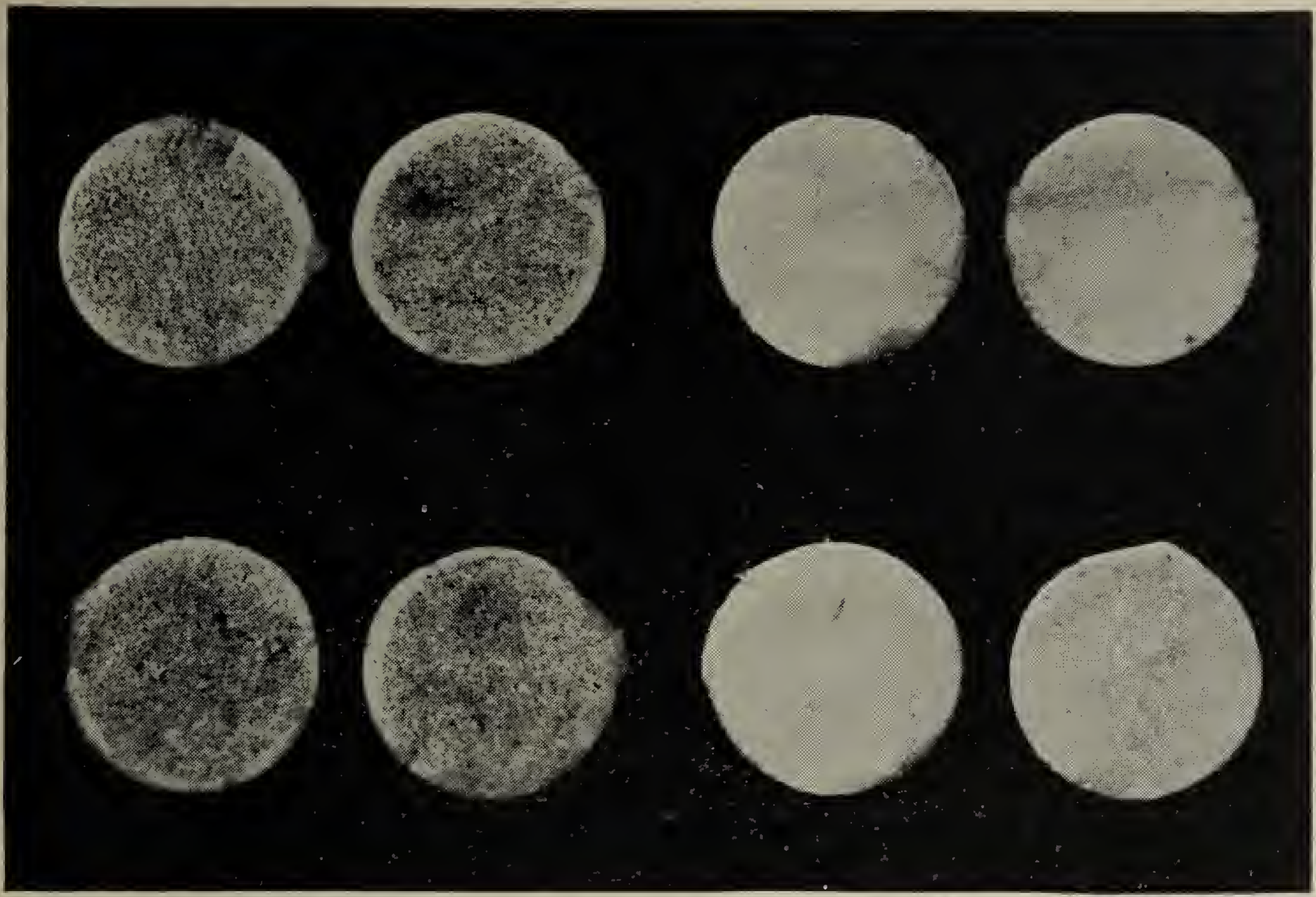

FIG. 133. AMOUNT OF INSOLUBLE DIRT IN UNCLARIFIED MILK AS COMPARED WITH THE SAME MILK AFTER CLARIFICATION

milk were tested before and after clarification, and, as shown in the illustration, the milk was much cleaner after clarification than before.

Amount of cream separated.— The most important physical effect, and probably the greatest of all effects, produced in milk by clarification is on the amount of cream that will rise on a given quantity of clarified milk as compared with the amount of cream from the same quantity of unclarified milk. Straight-sided graduated cylinders of 100 cubic centimeters capacity (fig. 134) were filled with samples of clarified and of unclarified milk. The cylinders were kept at a certain temperature for twenty-four hours, at the end of which time the amount of cream on the different samples was read and recorded. The results of this experiment are shown in table 11 and in figure 135.

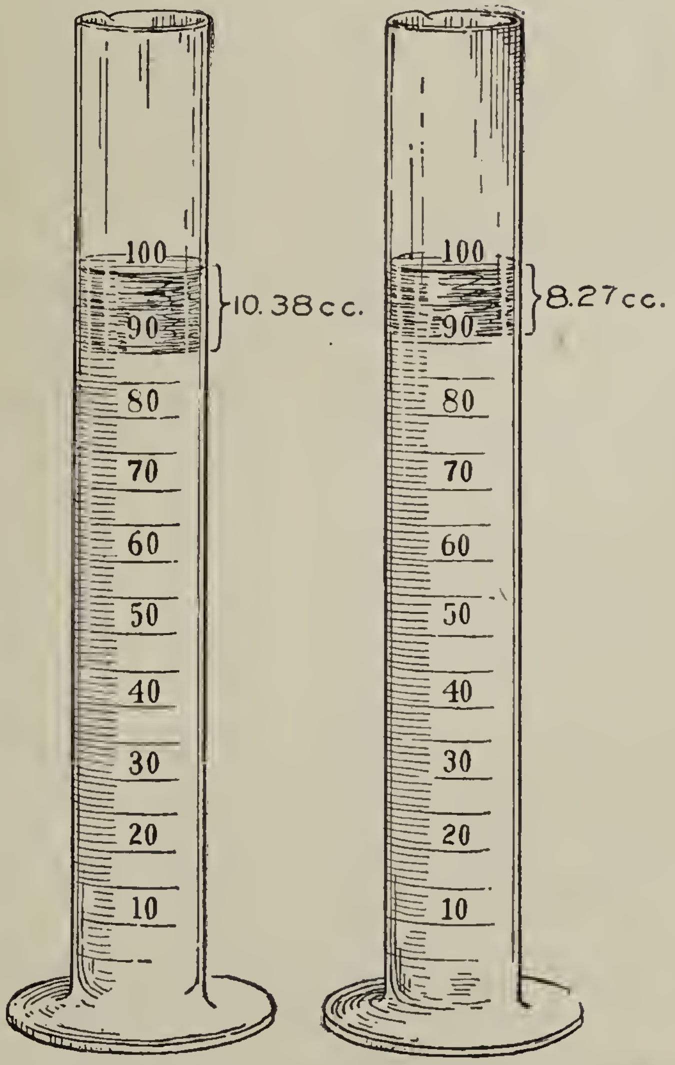

FIG. 134. CYLINDERS SHOWING AMOUNT OF CREAM RAISED ON 100 CUBIC CENTIMETERS OF MILK

TABLE 11. Effect of Clarification on Volume of Cream

Experiment	Cream raised		
	On unclarified milk (per cent)	On clarified milk (per cent)	Decrease (per cent)
1	6	5	1
2	6	4	2
3	8	6	2
4	8	7	1
5	13	9	4
6	13	11	2
7	11	7	4
8	9	6	3
9	11	9	2
10	11	8	3
11	14	10	4
12	8.5	6	2.5
13	12	9	3
14	11	10	1
15	6	5	1
16	10.9	6.6	4.3
17	10	9	1
18	11	9	2
19	8	5	3
20	12	10	2
21	9	7	2
22	10	8	2
23	8	7	1
24	10	8	2
25	10	8	2
26	10	9	1
27	10	8	2
28	10	9	1
29	6	5	1
30	6	5	1
31	12	9	3
32	15	13	2
33	18	15	3
34	15	13	2
35	15	14	1
Average	10.38	8.27	2.11

Every experiment of the thirty-five shows a decrease in the volume of cream raised on the clarified milk as compared with the unclarified milk. This may be explained in the following way: When the milk is passing thru the clarifier, it is subjected to a centrifugal force so great that the fat globules become broken up; so that where there were a few large globules before clarification, there are many small globules after clarification. The small globules have more surface according to their size, and this great increase in surface prevents or retards their rising;

while the large globules, which have a lesser surface in proportion to their volume, will rise to the top.

Kilbourne (1915), working for the New York City Board of Health, found that when milk was cleaned by the centrifugal clarifier the volume of cream separated was reduced by from 2 to 3 per cent.

The fact that clarification does affect the cream line of the milk is of commercial importance, because if the consumer does not see a good cream line on the top of the milk he naturally infers that the cream, or fat, is not there. That none of the fat is removed by clarification, however, is proved by table 6 (page 497). This shows that the fat content of the milk, as determined by the Babcock method, is the same after clarification as it was before. Therefore, even tho a smaller percentage of cream rises on the clarified milk, it does not mean that there is a smaller percentage of fat present.

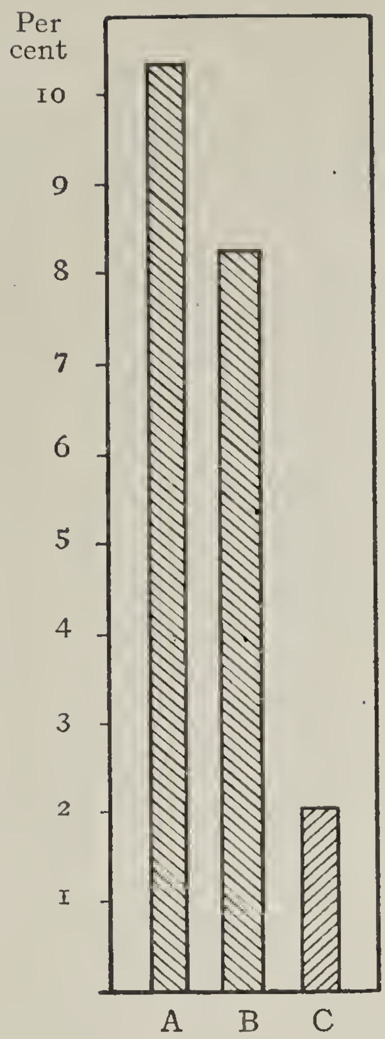

FIG. 135. PERCENTAGE OF CREAM RAISED ON UNCLARIFIED MILK AS COMPARED WITH THE SAME MILK AFTER CLARIFICATION

A, Cream on unclarified milk; B, cream on clarified milk; C, decrease due to clarification

CONCLUSIONS

When fresh milk is clarified, altho the bacteria count may be increased 100 per cent the final count is likely to be not over 10,000 bacteria per cubic centimeter, the average percentage of increase in these experiments being 87.15.

The percentage of increase in bacteria content by clarification is greater in the case of old milk than in the case of fresh milk. This is probably due to the high initial count in old milk. In these experiments the average percentage of increase for the old milk was 114.77.

Bacteria increase more rapidly in unclarified milk than in clarified milk.

The fat content before and after clarification is practically the same.

The percentage of total solids is slightly reduced by clarification. This is probably due to the slime removed.

The development of acidity is slightly more rapid in clarified milk than in unclarified milk.

The keeping quality of milk remains about the same after clarification as it was before.

About 99 per cent of the insoluble dirt in milk is removed by clarification.

The volume of cream that is separated by gravity is reduced from 2 to 3 per cent by clarification. This is probably due to the agitation of the milk in passing thru the clarifier.

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THREE CEDAR RUST FUNGI THEIR LIFE HISTORIES AND THE DISEASES THEY PRODUCE

JAMES LeROY WEIMER

ITHACA, NEW YORK
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THREE CEDAR RUST FUNGI

THEIR LIFE HISTORIES AND THE DISEASES THEY PRODUCE[1]

JAMES LEROY WEIMER

The three fungi considered in these investigations are *Gymnosporangium Juniperi-virginianae* Schw., *Gymnosporangium globosum* Farlow, and *Gymnosporangium clavipes* C. & P. Except for a discussion of the hosts concerned, the fungi, together with the diseases that they produce, are treated separately.

HOSTS

Certain species of the genus Juniperus on the one hand and various species of the family Rosaceae on the other, serve as hosts for the alternate stages in the life cycles of the fungi named above. In the telial stage all three species occur on *Juniperus virginiana* L. Kern (1911)[2] reports *G. Juniperi-virginianae* and *G. globosum* also on *J. barbadensis* L., and *G. clavipes* on *J. communis* L. Several horticultural varieties of *J. virginiana* are also known to be hosts. In this discussion, however, only *J. virginiana* will be considered as the telial host since it is the only species common in central New York State, in which locality the investigations were made.

In their aecial stage these fungi occur on certain closely related members of the family Rosaceae. Among these are the cultivated and the wild varieties of apple (*Pyrus malus* L.) and crab apple (*Pyrus coronaria* L.), quince (*Cydonia vulgaris* Pers.), pear (*Pyrus communis* L.), June berry (*Amelanchier* spp.), mountain ash (*Sorbus* spp.), and numerous species of Crataegus.[3]

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[1] Also presented to the Faculty of the Graduate School of Cornell University, May, 1916, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

AUTHOR'S ACKNOWLEDGMENTS. Grateful acknowledgment for assistance and suggestions is made to Professor H. H. Whetzel; to Dr. V. B. Stewart for help and criticism in preparation of the manuscript; and especially to Dr. Donald Reddick, under whose immediate direction the work was performed.

[2] Dates in parenthesis refer to *Literature cited*, page 548.

[3] For a more complete list of hosts see Kern (1911).

THE DISEASE CAUSED BY GYMNOSPORANGIUM JUNIPERI-VIRGINIANAE

The disease caused by the fungus *Gymnosporangium Juniperi-virginianae* is generally known as *cedar rust*, although the galls are referred to as *cedar apples* or, more rarely, as *cedar flowers*. The term *apple rust* is most commonly applied to the accial stage. Other names, such as *leaf rust*, *stem rust*, *fruit rust*, and *orchard rust*, are sometimes used to designate this disease.

HISTORY AND GEOGRAPHICAL DISTRIBUTION

The fungus is native to North America and has never been reported elsewhere so far as the writer has knowledge. Although it had already been known for a long time, it received but little attention prior to the work of Farlow in 1880. During the last decade, numerous investigations have been conducted bearing on the life history of the organism and on methods of control of the disease on the apple.

The apple rust stage is widely distributed throughout the eastern half of the United States wherever cedar and apple occur together.[4]

ECONOMIC IMPORTANCE

Owing to the fact that cedar trees occur in considerable numbers in but few States, apple rust has become of great economic importance only in certain localities. In some of the Southern States, where cedars grow in close proximity to the orchards, the disease causes an annual loss aggregating several thousand dollars, and there is considerable evidence that it is becoming more destructive each year. Pammel (1905) had never observed this rust on cultivated apples in Iowa prior to 1905. Emerson (1905), speaking of conditions in Nebraska, G. E. Stone (1911) in Massachusetts, and Giddings and Neal (1912) in West Virginia, state that the disease is becoming more serious each year. Stewart (1910) records several outbreaks in New York State, but says that the disease is rarely of much economic importance. R. E. Stone (1908) in Alabama, and Reed and Crabill (1915) in Virginia, list this as the most serious disease of apples in their respective States. In central New York the disease is very common on wild species of apple but is seldom found on cultivated varieties. The writer had two orchards under observation during the seasons of 1914 and 1915, one of which contained numerous cedar trees that were affected with *G. Juniperi-virginianae*, *G. globosum*, and *G. clavipes*, while the other was only about a half mile distant from a cedar grove that was severely infested with these three species of rust fungi. No affected apple leaves or fruit were found in either orchard. A few affected leaves and two affected apples were found in the Cornell University orchard in 1914.

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[4] For limits of geographical distribution see Kern (1911).

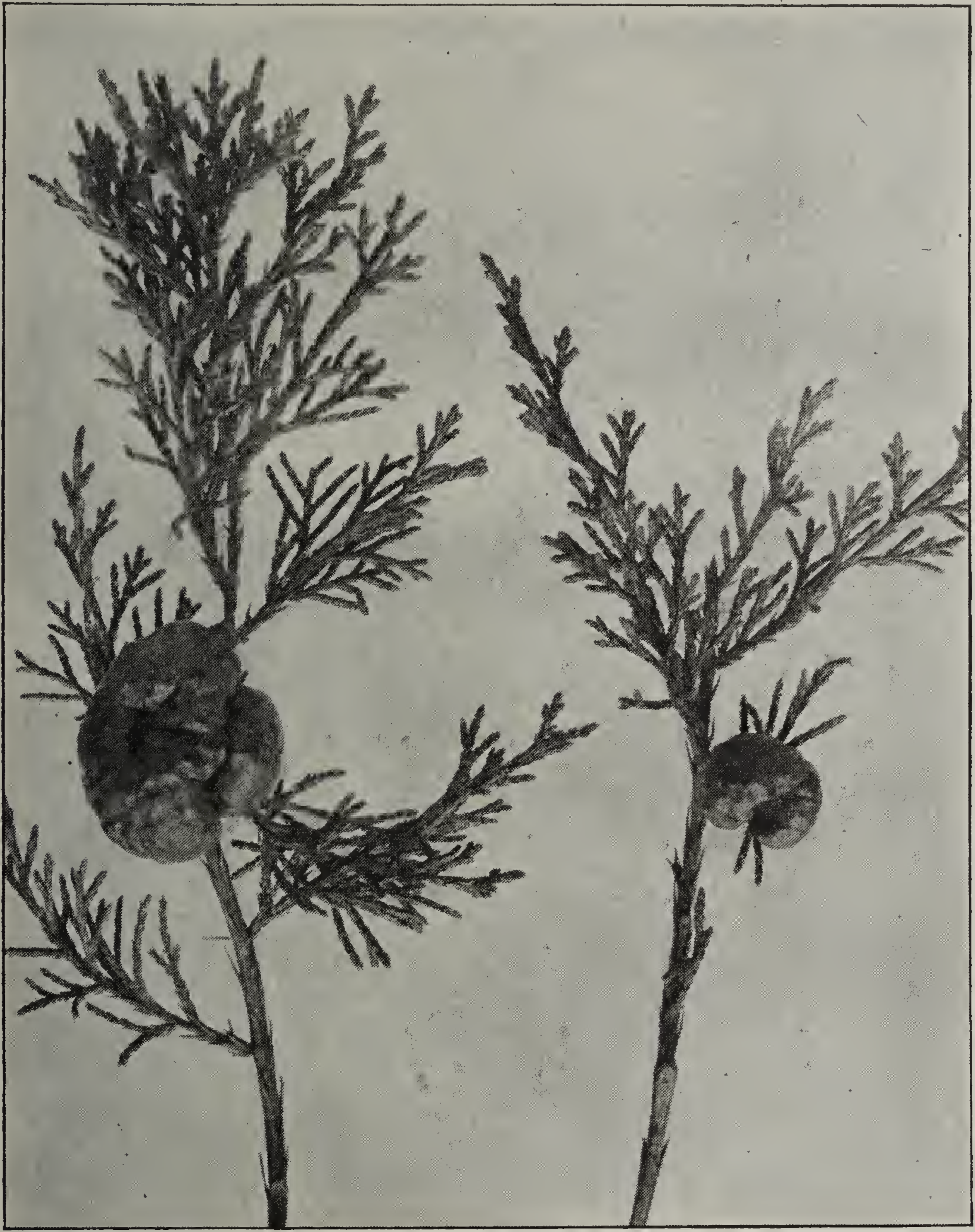

FIG. 136. GALLS OF GYMNOSPORANGIUM JUNIPERI-VIRGINIANAE
The galls are in the winter condition and show the depressions from which the telial horns protrude in the following spring

NATURE OF LOSSES

Although the greatest loss from this rust occurs on the apple, cedar trees also may be materially injured. The injury to apple trees caused by the disease is largely due to premature defoliation and to a reduction in the vital activities of the less seriously affected leaves. Premature defoliation year after year greatly reduces the vigor of the trees and death may finally result. Reed, Cooley, and Crabill (1914) state that where the disease is severe for several years in succession the trees make but little growth, become much weakened, and are more subject to attacks of insects and of other fungi. Another source of loss is due to the deformation of the affected fruit, such fruit in most cases being unsatisfactory for

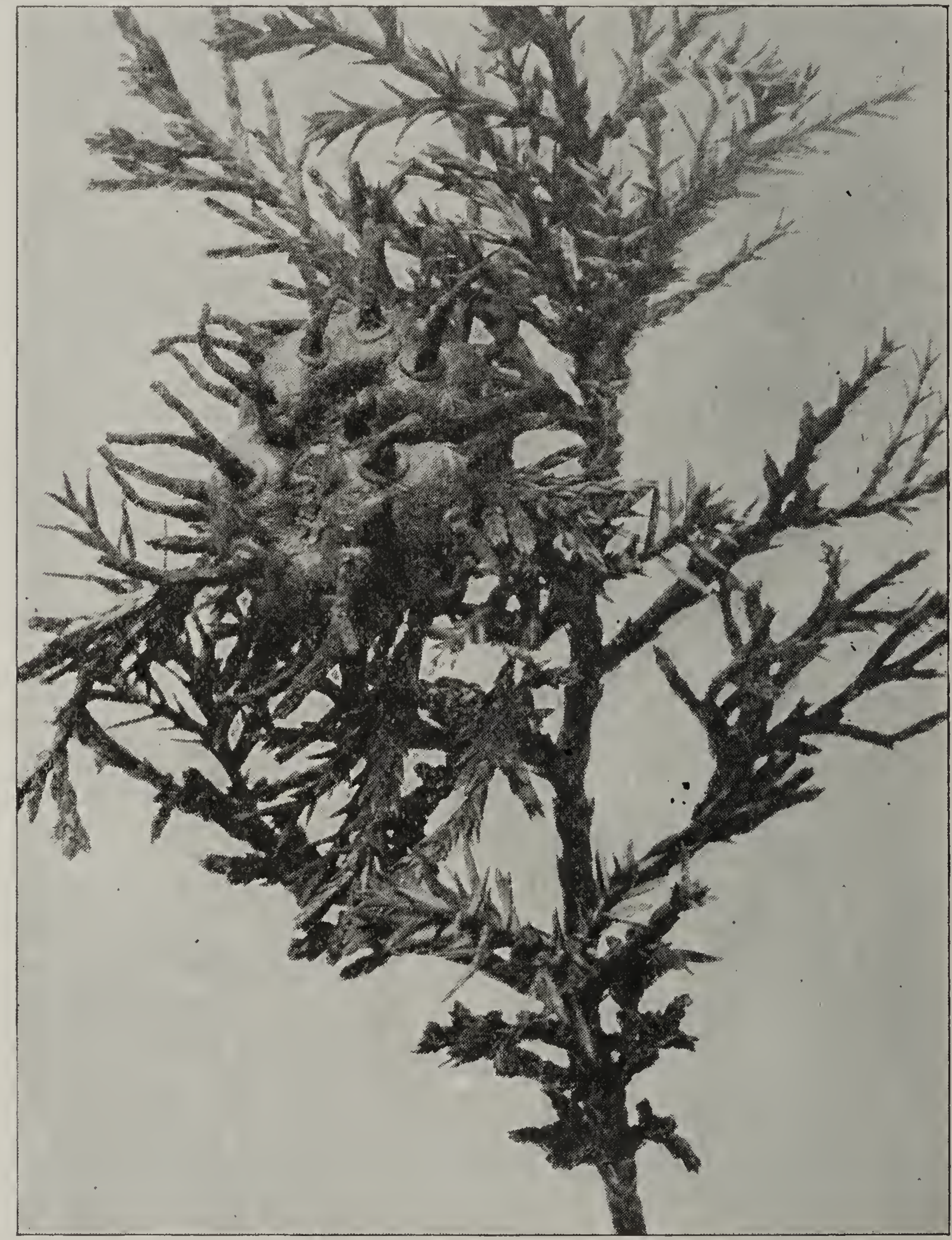

FIG. 137. TELIAL HORNS OF GYMNOSPORANGIUM JUNIPERI-VIRGINIANAE
The telial horns are shown as they appear after one gelatinization period

market. The young twigs may also become affected[5] and die; in many such cases death of a tree may ensue before it reaches bearing age.

SYMPTOMS

On cedar

On the cedar tree the first evidence of the disease caused by *G. Juniperi-virginianae* is a minute greenish swelling on the leaf, usually noticeable first on its upper, or inner, surface. The affected part of the leaf enlarges rapidly and becomes gradually darker in color, and by the last of September a nearly full-grown cedar apple is formed. At this time the gall is greenish brown in color, from globose to reniform in shape, and of a diameter varying from two millimeters to five centimeters. In New York State the slight pit-like depressions in the outer surface of the gall appear about October 1 (fig. 136). In the following spring the telial horns protrude from the depressions. These horns are golden brown in color and cylindric-acuminate in shape (fig. 137). During warm spring rains they gelatinize and enlarge about two to three times (fig. 138). Later the galls die, but often they remain attached to the cedar tree for a year or more.

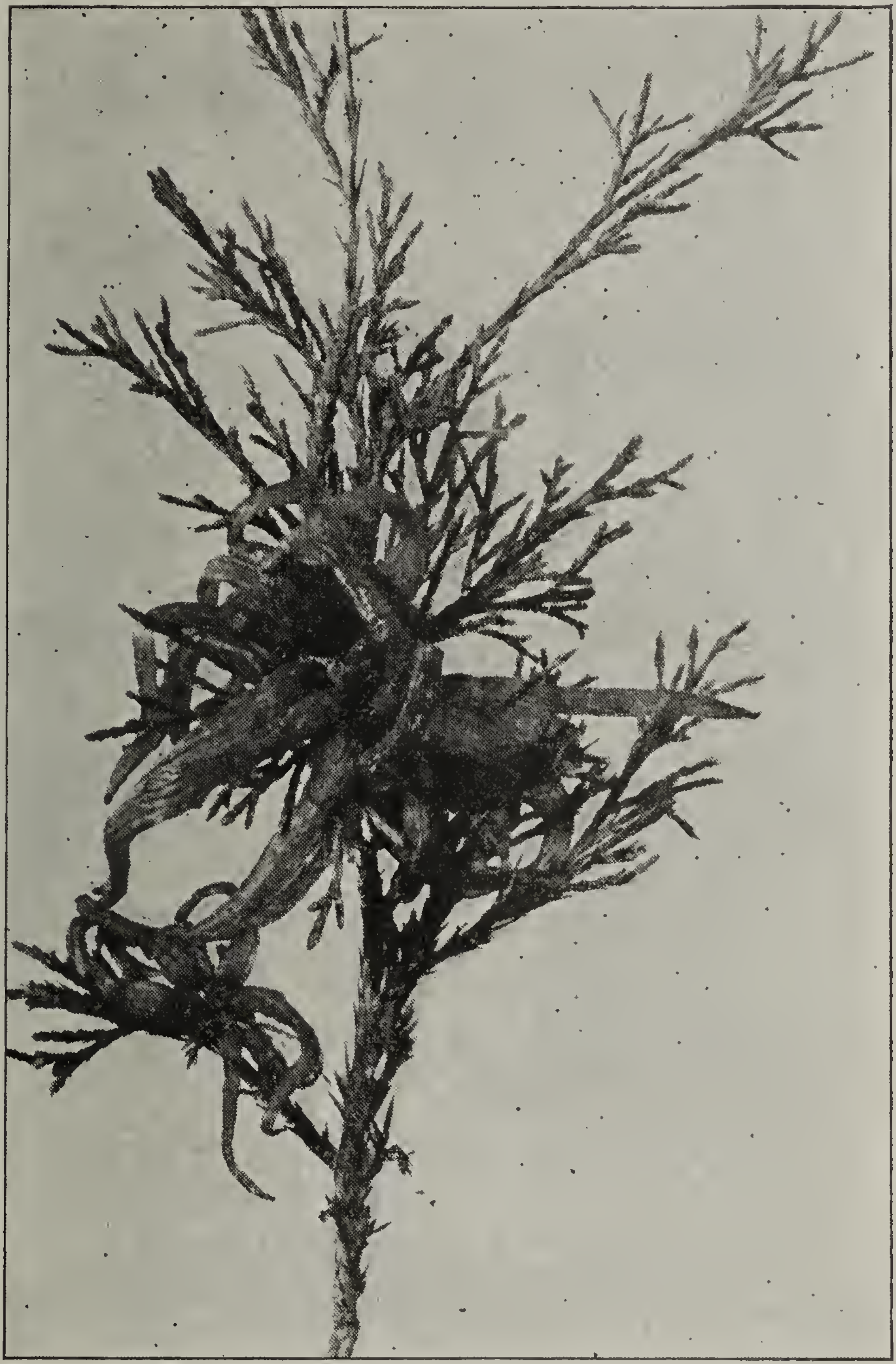

FIG. 138. GALL OF GYMNOSPORANGIUM JUNIPERI-VIRGINIANAE

The telial horns are shown as fully gelatinized

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[5] Twig infections of a wild variety of apple were very common at Ithaca, New York, during the summer of 1914.

On apple

On the leaves

The first evidence of infection by *G. Juniperi-virginianae* on the apple leaf is the appearance of very small greenish yellow spots about one-half millimeter in diameter. These spots gradually enlarge and the color changes to orange-yellow often bordered by concentric red bands (fig. 139).

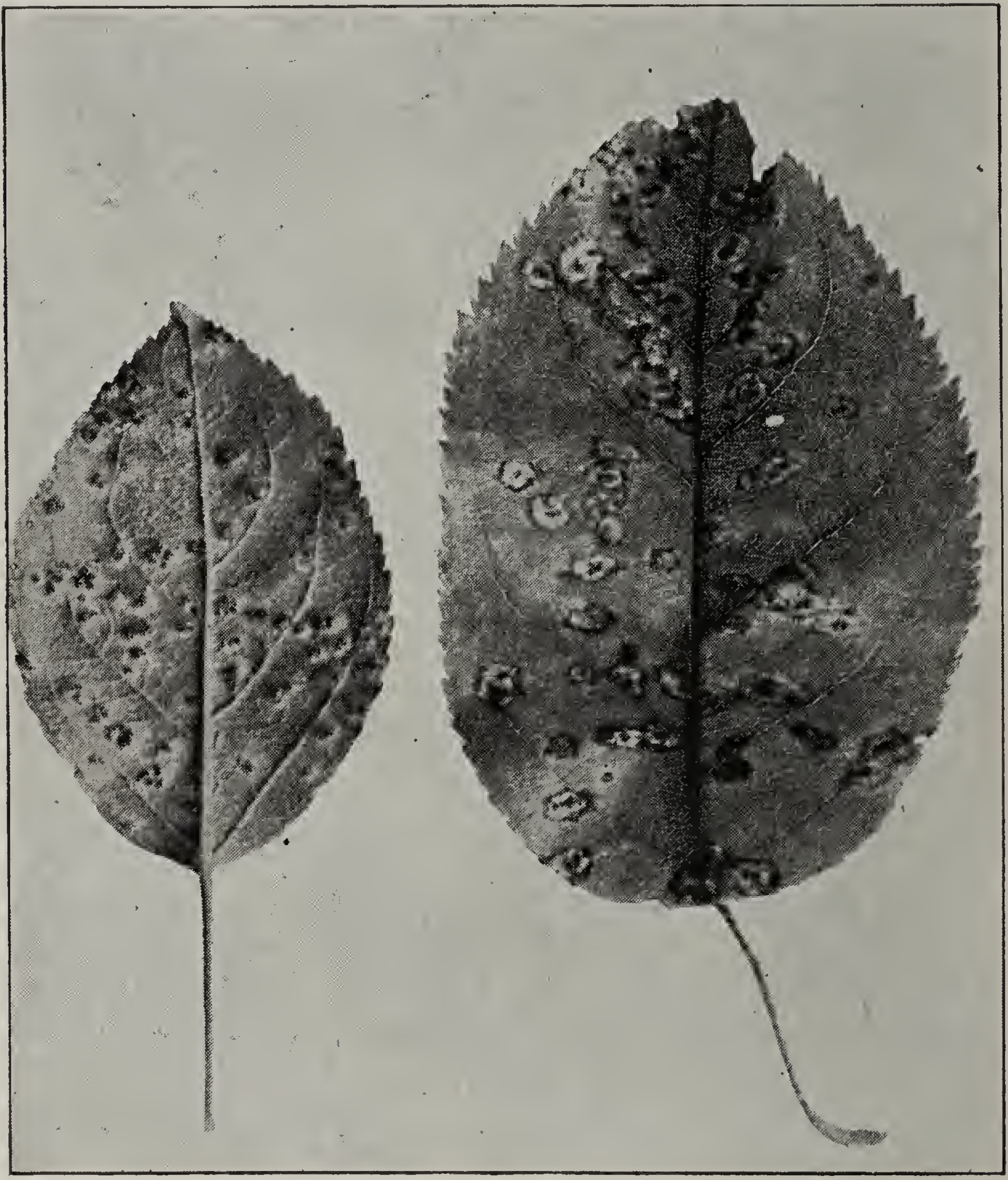

FIG. 139. APPLE LEAVES AFFECTED WITH GYMNOSPORANGIUM JUNIPERI-VIRGINIANAE

The characteristic lesions of the rust are shown on both sides of the leaves

In these lesions minute yellow pycnia soon appear, which vary in number according to the size of the affected area. After a few days the pycnia exude droplets of a yellow, sweetish substance, and soon afterward they turn black. The underside of the lesion becomes hypertrophied about this time and the aecia soon appear. These may be arranged in a circle near the margin of the swollen area or they may be scattered over the lesion.

On the fruit

The lesions on the fruit are similar to those on the leaves except that normally they are larger and bear a larger number of aecia (fig. 140). The spots are yellow and wrinkled, and as a rule are confined to the blossom end of the fruit although they may occur on the sides or on the stem end. Affected apples may be dwarfed and deformed.

On the twigs

In apples of very susceptible varieties twigs of the current year's growth may be severely affected by the rust. Infection takes place early in the season. The twig does not elongate, but it increases in diameter, and as a result a short, thick, stubby twig is produced in which pycnia and aecia are formed in abundance. Seriously affected twigs die at the end of the season.

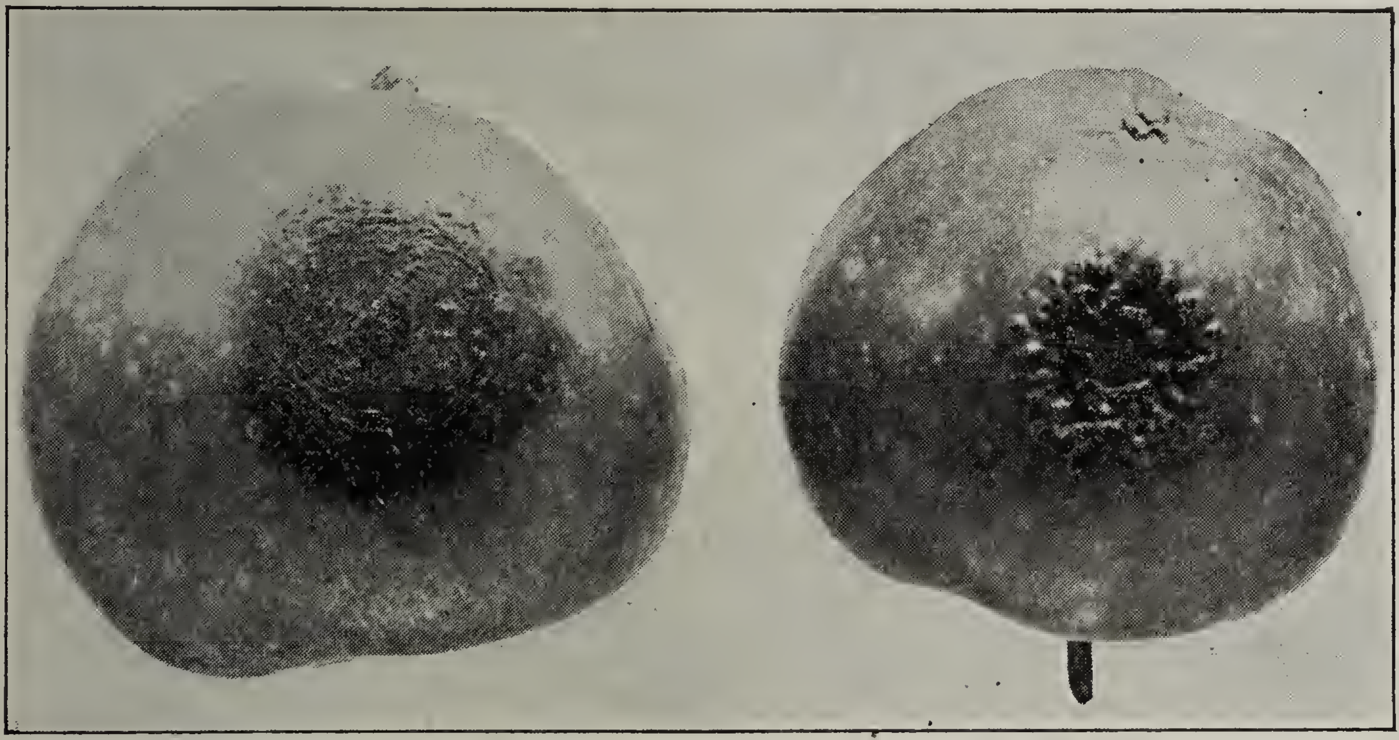

Fig. 140. APPLE FRUIT AFFECTED BY GYMNOSPORANGIUM JUNIPERI-VIRGINIANAE
The apple on the right shows the aecia protruding from the surface, while the apple on the left shows only pycnia

ETIOLOGY

Nomenclature

The cedar fungus was first named *Gymnosporangium Juniperi-virginianae* by Schweinitz in 1822. In 1825 it was named *G. macropus* by Link, but *G. Juniperi-virginianae* is considered the accepted name.

Life history

Telial stage

Inoculation of cedar.— According to Kern (1911), Plowright was the first to infect cedar trees with a rust fungus. On June 25, 1884, he inoculated a small one-year-old juniper seedling, about 2.5 centimeters high, with

G. clavariaeforme (Jacq.) DC. Evidence of infection was apparent on July 1 but the tree died before any spores were formed. In another instance Plowright inoculated a tree 3 decimeters high and spores were produced one year from the following spring, showing that nearly two years are necessary for the completion of the life cycle of the fungus. Heald (1909) failed to obtain infection in cedars with *G. Juniperi-virginianae*.

Each summer for the past three years, small cedar trees growing in the greenhouse have been inoculated by the writer. The methods used in making the inoculations were for the most part those employed by Kern (1911) in infecting aecial hosts. Aeciospores were scraped from an affected apple leaf into tap water, and the suspension of spores thus obtained was sprayed on a cedar tree with an atomizer. Other affected leaves were suspended over the tree so that the spores fell directly on it. After the tree was sprinkled with the infected water it was covered with a large bell glass so that the moisture would be retained. Each day the bell glass was removed and the inner surface sprayed with water, in order to maintain a moist atmosphere. After a period varying from forty to sixty hours the bell glass was removed.

In the autumn of 1914 five trees were thus inoculated. The results are recorded in table 1:

TABLE 1. Inoculation of Cedar Trees with Spores of Gymnosporangium Juniperi-virginianae in 1914

Number of trees inoculated	Date of inoculation	Number of infections apparent	Fungus
3	July 25	1, on July 30, 1915*	*G. Juniperi-virginianae*
1	September 8	No infection	*G. Juniperi-virginianae*
1	September 27	No infection	*G. Juniperi-virginianae*

* See discussion of this case in the text, page 517.

All the inoculated trees were examined carefully on November 6, 1914, but no sign of infection was evident. In one case certain parts of several leaves were yellowish green in color, closely resembling infected leaves, but there was no further development and the leaves finally died. On July 26, 1914, two cedar trees which had been inoculated with *G. Juniperi-virginianae* the previous autumn showed certain leaves that appeared to be infected. Leaves on different stems showed yellow discolorations, while the other leaves were of the normal green color. Although the leaves with the discolored spots died without showing further evidence of infection, it is possible that the fungus was more virulent under these conditions and killed the leaves without showing any signs of gall development. None of the foliage on the check trees showed the yellow discoloration.

On July 30, 1915, a small cedar apple was found on a cedar tree that had been inoculated on July 25, 1914, by suspending over the tree the fruit of an apple infected with *G. Juniperi-virginianae.* When first observed this gall was one millimeter in diameter, globose, and green in color. It appeared to be developing from the upper, or inner, side of a small scale leaf. This tree was brought into the greenhouse in the early spring of 1914 and all cedar apples were removed. It was carefully examined again on April 10, 1915, for any signs of cedar apples and none were found. That this gall could have been the result of natural infection before the tree was removed to the greenhouse seems impossible, since in that case it would have developed in the previous year. The gall was undoubtedly that of *G. Juniperi-virginianae*, as is evident by its method of origin, its color (at first green and later turning to the characteristic brown), and its surface character. By October 1 it had doubled in size, and spores were produced in February of 1916. Apparently the gall resulted from the inoculation. It is, however, impossible to determine this point absolutely.

Susceptibility of individual trees.— Observations made during the past three years seem to indicate that individual cedar trees show a difference in susceptibility. Some may be severely affected while others are practically free from the disease. Certain trees produce a considerable number of *G. Juniperi-virginianae* galls, while others bear almost exclusively the galls caused by *G. globosum*, and still other trees may be affected severely by *G. clavipes.* Furthermore, some of the trees may have all three species present in great abundance, but usually a tree is attacked primarily by a single species.

There is a wide variation in the number of cedar galls of *G. Juniperi-virginianae* produced from year to year. This variation usually depends on the abundance of the alternate stage in the preceding year. This is not always true, however, since favorable infection weather may not prevail at the time when infection of the cedar would naturally occur. In the summer of 1914 an abundance of the aecial stage of all three species was produced, and a corresponding increase in the number of cedar apples was apparent in the fall of 1915. There is less fluctuation in the case of *G. globosum* and *G. clavipes*, since these forms are perennial.

Infection period.— It is generally accepted that infection of the cedar may occur with the production of the first mature aeciospores, and continue throughout the season. During the seasons of 1915 and 1916 the aeciospores matured about August 1 in New York State. Many workers have had difficulty in germinating these spores, and for that reason Reed and Crabill (1915) have advanced the theory that a rest period is necessary and that the aeciospores do not germinate until the spring following their dispersal. It is probable that the mycelium develops within the tissue of the cedar for a period of several months after infection occurs, before any material change is noticeable. The galls first make their appearance in the latter part of July and continue to grow rapidly until late autumn, when they are practically mature.

Mycelium and haustoria.— Prior to the formation of telial horns, the mycelium is distributed throughout the gall. where it occupies the intercellular spaces. The entire leaf from which the gall originates is permeated with mycelium even before much hypertrophy or other change becomes evident. The mycelial cells vary in length and the septa are often difficult to locate. This fact undoubtedly accounts for the mistake of Sanford (1888) in thinking that no cross walls exist. The binucleated condition can readily be demonstrated. The hyphae vary in width but average about 2.5 μ.

Haustoria are present, but not abundantly in the young galls. Reed and Crabill (1915) give a detailed account of the formation of haustoria. They were able to find only the very early stages in the autumn, and believe that mature haustoria are not developed until just preceding teliospore formation in the spring.

Development of telial horns.— About the first of October or later, depending on the season, aggregates of mycelium are developed in certain areas, forming typical stromatic layers. The host cells in these regions are often completely insulated and very small. The rapidly forming mycelium inhibits the growth of the host cells in its midst, but the adjoining cells continue to multiply and enlarge so that a depression results. From these stromatic layers the teliospore stalks arise. Sections of galls collected early in December, 1915, show the spore stalks and the immature spores in abundance. The spores are cut off from the tips of the short stalk-cells by septa, and almost simultaneously become two-celled. The young spores contain two nuclei in each cell, but these fuse when the spores reach maturity.

In 1915 the more advanced galls showed the telial depressions about October 1. No further change was noticed until early in the following spring, when the telial horns pushed out from the depressions and continued to develop for some time. The telial horns consist of a vast number of spores borne on much elongated pedicels. They are first formed beneath the epidermal tissue, and when warm weather begins the pedicels elongate and carry the spores out with them. In 1914 the telial horns began to make their appearance about the middle of April, and mature spores were present on April 25 but gelatinization did not take place until May 5. In 1915 the epidermis was broken open about April 15 and the first gelatinization took place on May 8.

An experiment was conducted to determine whether or not the telial horns are capable of gelatinization as soon as they emerge from the gall. A cedar apple with horns not more than one millimeter in length was placed in a glass beaker containing water. Within less than half an hour the horns had swollen to twice their original size. Apparently the spore stalks are capable of gelatinization as soon as they have ruptured the epidermis of the gall, but an attempt to germinate the spores at this time failed.

The telial horns may become from 2 to 20 millimeters in length by 1.5 to 3 millimeters in width before the first gelatinization takes place. At this time the telial horns are cylindric-acuminate in shape. They are golden brown in color and are evenly distributed over the surface of the gall. With the first warm spring rains after the horns are protruded, they enlarge to as much as three times their original size. The horns during this period are of a jelly-like consistency and are much lighter in color than before, due to the fact that there is less coloring matter in the gelatinous spore-stalks than in the spores. With the return of drier conditions the horns regain approximately their original size. The tips of these protrusions usually dry down more than the remainder, and are often of a hard consistency. After each succeeding rain one-half hour or more in duration, gelatinization may occur, and this may be repeated as many as fifteen or twenty times. Nevertheless, some of these periods may not be of sufficient duration to permit the spores to germinate. In 1914 the first gelatinization took place on May 5, and after the horns had dried it was noted that for nearly one-fourth of their length from the apex to the base they were lighter-colored and much firmer in consistency than before gelatinization. After the rain period of May 21 about one-half of the horn was lighter-colored, and after the rain on June 5 only a small area at the base retained its original color and its ability to gelatinize. This basal part became swollen on two subsequent occasions, a smaller part each time, until finally the horn was light in color throughout and became detached from the gall on July 1.

A microscopical examination of the part of the horns which assumed a lighter color showed that approximately fifty per cent of the spores had germinated. It has been observed also that the spore stalks of germinated spores are unable to gelatinize. They become dry and hard, so that when they are teased apart and examined the empty spore walls are generally broken from their stalks or only short pedicels remain. It would seem from the foregoing observations that the horn becomes lighter in color and hard progressively from the apex to the base, and also that the spores at the apex are older, mature earlier, and germinate more readily than those at the base. Reed and Crabill (1915) are of the opinion that the teliospores on the outside of the tentacle germinate first and shrivel away, and then those on the interior of the tentacle come to the surface and germinate in their turn. The writer's observations show that, although the spores over the entire surface of the horn germinate, those at the apex germinate more readily. These observations agree with those of Wörnle (1894), who states that the spores at the apex are the oldest.

Teliospore germination.— The time of spore germination varies with the season. In 1914 and 1915 the spores were mature about April 25. Tests made show that the spores will not germinate as soon as the horns rupture the epidermis of the gall. Weather conditions are an important factor, and as much as two weeks may intervene before germination occurs. When cedar apples with telial horns that were just emerging were brought into the laboratory, the spores germinated after about seven days.

The teliospores are characteristically two-celled, but occasionally one-celled and three-celled spores are found (fig. 141, A). They range in width from 15 to 22 μ and in length from 33 to 65 μ.[6] The spore is narrowly ellipsoidal to rhombic oval in shape. It is slightly or not at all constricted at the septum. The wall is cinnamon brown in color and averages about 1 μ in thickness. The pedicels are thin and of equal diameter throughout, varying in width from 3 to 5 μ for different spores. There are two germ pores in each cell of the spore, one on each side of the cell near the septum. Spore germination is of the usual rust type, resulting in the formation of a promycelium bearing four basidiospores (fig. 141, B).

Heald (1909) found that under favorable conditions the promycelium and basidiospores may be produced in from twelve to twenty-four hours; Coons (1912) states that the process of developing germ tubes requires from six to fifteen hours; while Reed and Crabill (1915) found four hours to be the minimum time for germination. The writer has obtained mature basidiospores within less than three hours under optimum conditions; in fact, under such conditions from three to four hours is the usual time required.

The most satisfactory germination of teliospores was obtained from spores placed on a clean slide in a film of tap water. The slide was placed in a petri dish, which contained a small quantity of water to prevent too rapid evaporation from the slide. On one occasion a spore taken from a telial horn just brought in from the field on a clear day and germinating under the conditions described above, had formed a small bud-like process at the end of one hour; after two and one-half hours the promycelium had continued its development and the septa were visible; by the end of three and one-half hours the basidiospores were formed. Instances have been noted in which the spores germinated and the basidiospores were present within less than three hours.

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[6] Spore measurements were made in all cases with an oil-immersion lens, using fresh spores mounted in water.

One of the important factors affecting spore germination is the amount of moisture. Blackman (1903) discusses this subject in some detail. He used spores of other species of rust, placing some in hanging drops and some on slides in petri dishes. He found that those in hanging drops developed long germ tubes and formed no basidiospores until they had grown through the drop into the air, which rarely happened. The others formed basidiospores and a characteristic promycelium at once. Blackman concludes that the presence or absence of air is the determining factor, as this varies with the water supply.

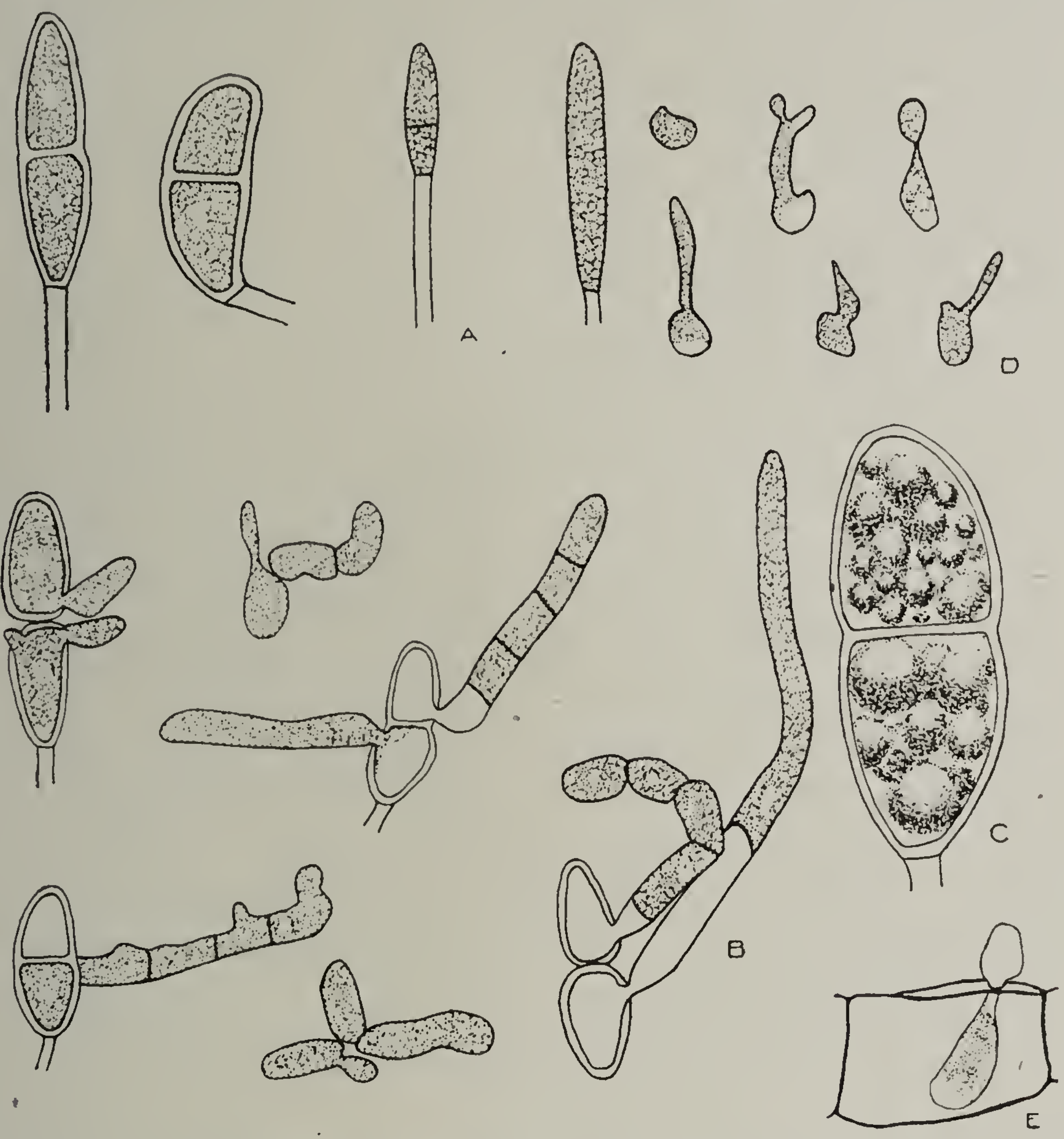

FIG. 141. SPORE FORMS OF GYMNOSPORANGIUM JUNIPERI-VIRGINIANAE

A, Various types of teliospores of *G. Juniperi-virginianae*. × 350. B, Various stages and types of teliospore germination of *G. Juniperi-virginianae*. × 350. C, Teliospore of *G. Juniperi-virginianae*, showing the appearance of the cell contents when incubated at 30° C. for four hours. × 375. D, Various stages of basidiospore germination of *G. Juniperi-virginianae*. × 350. E, Penetration of a basidiospore of *G. Juniperi-virginianae* directly through the wall of an epidermal cell. × 350

It has often been observed by the writer that teliospores germinating on a slide produce only long tubes when covered with water, but when there is only a small amount of water present the usual promycelium and basidiospores are formed. An attempt was made to germinate teliospores in a saturated atmosphere without permitting the spores to come into contact with other moisture than that in the atmosphere. This attempt failed, but in cases in which the air became supersaturated, and small droplets condensed on the slide, germination was obtained.

Temperature is another factor that plays a large part in spore germination. Reed and Crabill (1915) found that 15° C. was the optimum temperature for spore germination and 11.5° C. was the minimum. The upper thermal death point was 30° C.; the lower thermal death point was not determined, but it was much below freezing.

Considerable work has been done by the writer in an attempt to determine the most favorable temperature conditions for germination with the three rust species studied. For the first of these experiments the following method was used: Telial horns were placed in a watch glass in tap water and teased apart until several spores could be obtained in each drop of water. Suspensions of spores thus prepared were placed on slides in petri dishes and allowed to germinate at different temperatures. It was found after several trials that spores which had been broken entirely free from the horn or were isolated from all other spores did not germinate so readily as did those that remained clinging in groups. After repeated trials it was found that a better indication of spore germination could be obtained by placing a telial horn, or a part of one, on a slide. In this way more nearly normal conditions were maintained, but the larger number of spores made it impossible to estimate the percentage of germination except in a comparative way. In the case of *G. Juniperi-virginianae* an entire telial horn was placed on a slide, and often horns from the same gall were used in a series of tests. In the case of the other two species only parts of the horns were used. The quantity of basidiospores lying along the side of the horn on the slide was often used as a guide in estimating the relative amount of germination. Observations were usually made every hour, and the rate of germination for the entire period was considered in making the final comparisons.

The extremes found for all three species were practically the same as those found by Reed and Crabill (1915) for *G. Juniperi-virginianae*, the lowest temperature at which germination occurred being 7° C. and the highest 29° C., with the upper thermal death point 30° C. (fig. 142). The optimum temperature, however, as shown by these experiments, ranges from 22° to 25° C., the best germination taking place at from 23° to 24° C. These experiments were run in triplicate and were repeated on several occasions throughout the season, so that some temperatures were tried at least twelve times. In all cases the results obtained were uniform. Reed and Crabill (1915) found that a temperature above 20° C. greatly retarded the development of basidiospores and that no spores were produced when the temperature was above 24° C. In the writer's experiments an abundance of basidiospores were obtained at a temperature ranging from 22° to 25° C., and there were some at 26° C. After incubating at 30° C. no spores germinated, even when placed under optimum conditions. The oily contents of the spores coalesced into large drops, giving the appearance shown in figure 141, c (page 521). The normal variation is relatively great in tests of this kind, but the experiments were repeated a sufficient number of times to make the observations comparatively conclusive.

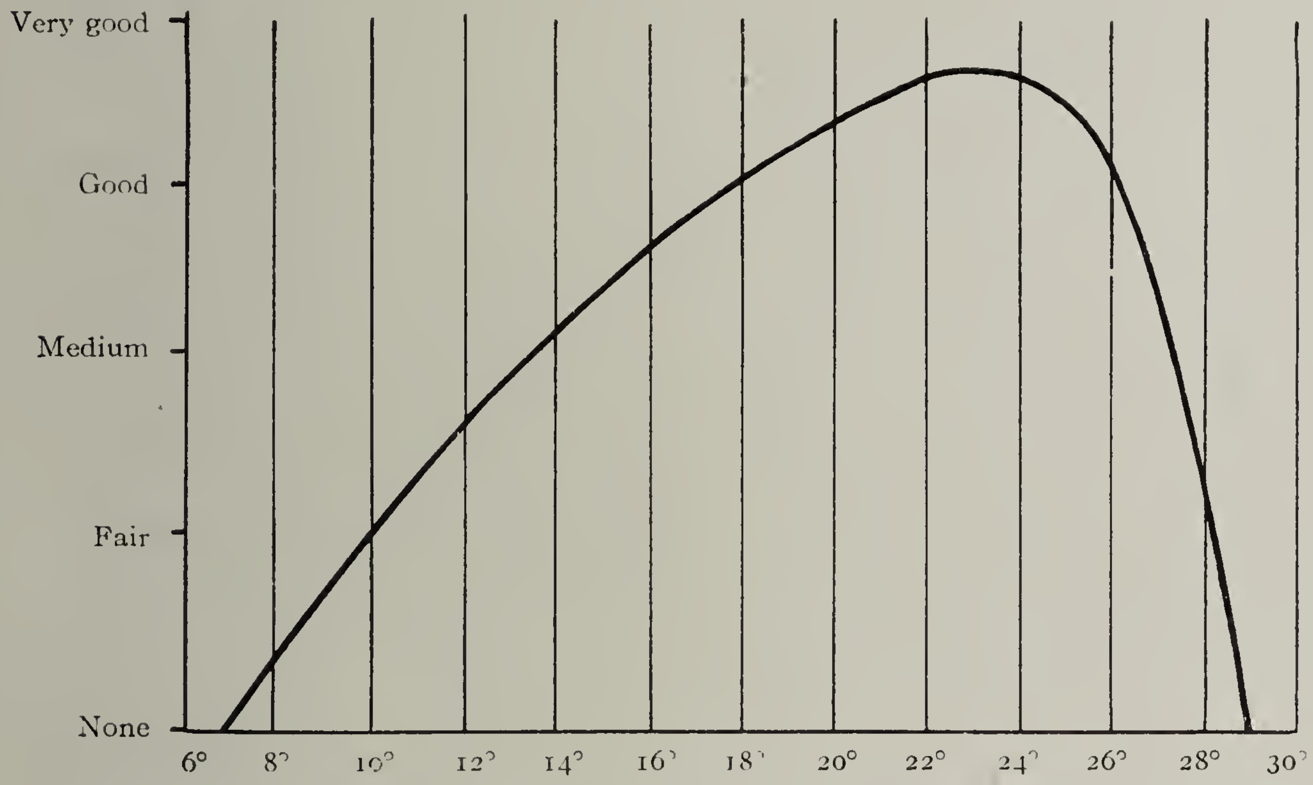

FIG. 142. INFLUENCE OF TEMPERATURE ON GERMINATION OF RUST SPORES
The curve shows that the best germination of teliospores occurred at a temperature between 22° and 24° C.

When conditions are unfavorable for germination a long germ tube may be formed or a bud-like process may take the place of a promycelium. Again, the promycelium may break up into four parts, each of which may then form a basidiospore or may germinate by a germ tube. The cells of the promycelium may germinate by germ tubes without breaking apart, or other uncommon methods of germination may occur. These abnormal conditions of germination are usually found where an overabundance of moisture is present or where the temperature is somewhat lower than the optimum.

Dissemination of basidiospores.— When the basidiospores reach maturity they are forcibly discharged from their sterigmata. With the beam-of-light method the falling of basidiospores was observed by the writer in the same manner as is described by Buller (1909) and later by Coons

(1912). An experiment was set up in which the discharge of basidiospores began at half past six o'clock in the evening of one day and continued until after ten o'clock the next forenoon — although at that time the rate of discharge was much slower. Evidently the dispersal of basidiospores can continue for some time after a period of rainfall if slow-drying conditions prevail. In observing the process under the microscope an abrupt sidewise movement of the basidiospore was always noticed several seconds previous to its discharge, and almost simultaneously a bubble appeared at its base.

The basidiospore farthest from the spore is the first to be formed, followed by the others in their respective order. The outermost spore is discharged first, followed by the next in order. Only about one minute elapses between the disappearance of the apical basidiospore and the one nearest it, but a much longer period elapses before the last two are discharged. Often the terminal basidiospore is mature before the sterigma of the basidiospore nearest the spore is even formed. This method of discharge readily accounts for the wide dissemination of basidiospores by air currents.

Germination of basidiospores.— Farlow (1886), Crabill (1913), and Reed and Crabill (1915), have contributed to the knowledge of secondary basidiospore formation. The basidiospore normally germinates by the development of one or more, rarely two, germ tubes from the side of the spore. Under certain conditions, instead of a germ tube a sterigma similar to those formed on the promycelium is put forth, and on the end of this a secondary basidiospore is produced. This secondary spore is identical in appearance with its parent except that it is somewhat smaller. Various stages of basidiospore germination are seen in figure 141, D (page 521). The chief factor influencing the production of the secondary spore is an excess of moisture.

Two cedar apples, one caused by *G. Juniperi-virginianae* and the other by *G. globosum*, with horns protruded, were subjected for twelve hours to a fine mist from a spray nozzle attached to a water tap. The temperature of the room was 23° C. and that of the water about 8° C. When the material was examined it was found that a large number of the spores had germinated abnormally, and that the basidiospores which were formed had already germinated by means of secondary spores. It is impossible to determine whether or not the excess moisture was the only cause of this abnormal germination, since the temperature factor may also have been of importance.

Aecial stage

Inoculation and infection of apple.— The first basidiospores are usually disseminated in the spring about the time when the buds of the aecial hosts open, though some may be formed previous to this time. Infection usually occurs on the dorsal surface of apple leaves. The germ tube penetrates the epidermis and the pathogene becomes established within the tissues of the host.

In these inoculation experiments a suspension of basidiospores in tap water was placed on various parts of both the upper and the lower surface of Wealthy apple leaves. After seven, fourteen, and twenty-one hours, respectively, parts of the leaves thus inoculated were removed, fixed, and embedded in paraffin. Several of these were later sectioned and examined. In one case, after a period of seven hours a germ tube of a basidiospore was found to have penetrated the lower epidermis directly and passed about two-thirds of the distance through the epidermal cell (fig. 141, E, page 521).

Several leaves from a small apple tree were inoculated by placing basidiospores in suspension on the foliage, with a camel's-hair brush. Some leaves were inoculated on the upper surface and others on the under surface. Infection was apparent after ten days on all the inoculated leaves. This demonstrates that infection can take place on either the upper or the lower surface of the leaf. In all cases, however, pycnia were produced only on the upper surface. Apparently, therefore, the production of pycnia on the upper surface of infected leaves is due, not to the fact that infection occurs there, but to some other factor. Pycnia have never been seen on the lower surface of leaves, although many aecia have been observed arising vertically from the upper surface.

In 1914, and also in 1915, the first evidence of infection in nature was found about June 1. The mycelium is similar to that found in the telial hosts except that it is uninucleate and only a limited area of the host tissue is invaded.

Effect of environmental factors.— It is evident that the amount of rust present in a given season will depend largely on weather conditions. Moisture is necessary for teliospore germination and for infection of the aecial host, and therefore the number of infection periods depends primarily on the number of rain periods.

An attempt was made in these experiments to determine the approximate amount of moisture necessary for infection of the aecial host. Cedar apples were immersed in tap water for a few minutes and were then placed under a bell glass. After about four hours, when an abundance of basidiospores were being discharged, the gall was suspended over a small apple seedling. A lamp chimney inclosed both the seedling and the gall. The seedling was not moistened. The cedar apple retained its moisture for a long time in this position, and the basidiospores formed a yellow coating over the surface of the leaves of the seedling within a few hours. After eighteen hours the chimney was removed, and ten days after inoculation abundant infection was evident on nearly all the leaves. This experiment was repeated several times and in each case the same results were obtained. Apparently sufficient moisture collected on the leaves from the water transpired and from that which evaporated from the telial horns to permit basidiospore germination and infection. A careful inspection failed to disclose any drops of water collected on the leaves inside the chimney.

Other experiments were attempted in which the lamp chimney containing the cedar apple was suspended over the apple tree so that the basidiospores fell on the tree but no opportunity was offered for the condensation of water on the leaves. No infection occurred under these conditions. This experiment was repeated on a large tree in the open. The basidiospores were allowed to fall on a few young leaves which were not inclosed within the chimney. On the night when the experiment was set up there was a heavy dew followed by forty-eight hours of precipitation. Abundant infection occurred and aecia were developed within the usual period of time.

From these experiments it is evident that but little moisture is necessary for infection. There must be sufficient moisture to cause the telial horns to gelatinize and to keep them in that condition for a period of from four to five hours, followed by conditions of high humidity to furnish the necessary moisture for infection. This is contrary to the opinion of Reed and Crabill (1915), who state that infection takes place only in the presence of abundant moisture. It is not clear whether they mean to include the whole process of basidiospore formation and infection or only the latter, since they also make the statement that infections followed short periods of rainfall.

Strains of the fungus.— Since this disease is so destructive in West Virginia and Nebraska, specimens of cedar apples from each of these States were procured for the purpose of making comparative inoculation tests with the strain of the fungus found in the vicinity of Ithaca, New York. These specimens, obtained through the kindness of N. J. Giddings and E. M. Wilcox, were used to inoculate Wealthy apple trees in the open and apple seedlings in the greenhouse. Young leaves on different branches of each tree were inoculated with the three strains of fungi and their development was observed closely. Infection was apparent at exactly the same time in all cases and the development of the disease was identical in all particulars. In no case was there any evidence to show that one strain was more virulent than the others. The apples of West Virginia and of Nebraska may be more susceptible than those of central New York, which probably accounts for the fact that this disease is so destructive in the former States.

Varietal susceptibility of apple.— Numerous lists of susceptible and of resistant varieties of apples have been recorded by various writers. The most important of these are by Emerson (1905) in Nebraska, Chester (1896) in Delaware, R. E. Stone (1908) in Alabama, Smith and Stevens (1910) in North Carolina, Reed, Cooley, and Crabill (1914) in Virginia, and Giddings and Berg (1915) in West Virginia. Stewart (1910) says that in New York State the varieties Wealthy, Boiken, and Rome are very susceptible, Hubbardston and Sutton are slightly susceptible, and McIntosh, Yellow Transparent, Gravenstein, Red Astrachan, Oldenburg, and Baldwin are resistant. The writer has had no opportunity to make observations on the susceptibility of different varieties of apples, but the following have been artificially infected several times: Wealthy, Wagener, Twenty Ounce, Tompkins King, Alexander, Baldwin, Rome Beauty, Bietigheimer, Baxter, Boiken, Banana, Black Gilliflower, Dartmouth.

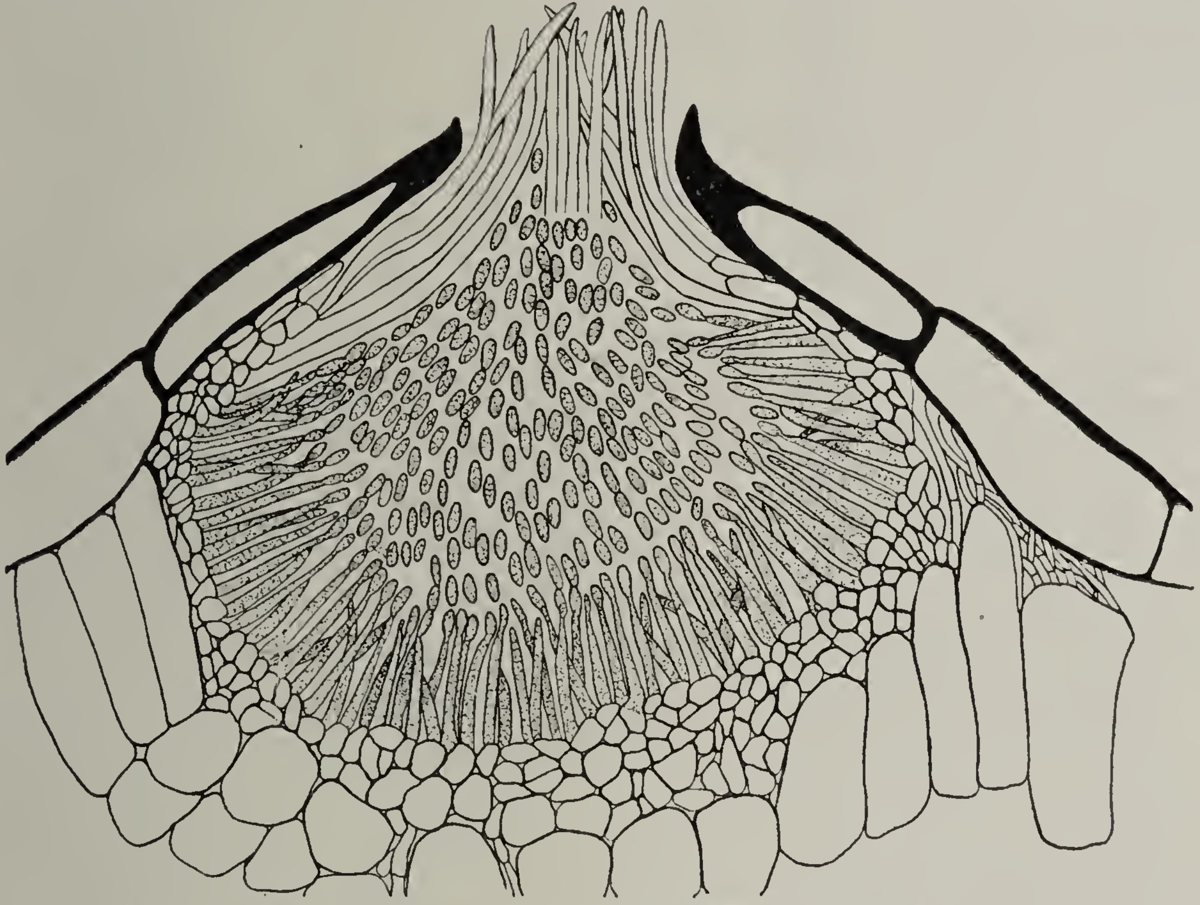

FIG. 143. PYCNIUM OF GYMNOSPORANGIUM GLOBOSUM IN CRATAEGUS LEAF. × 350

The variety Wealthy is considered especially susceptible, although Stewart and Carver (1896) state that it proved to be resistant in Iowa. Seedling apples are very susceptible when artificially inoculated.

Several specimens of Salome apples were received in the autumn of 1913 and a large rust lesion was present on the blossom end of each. This variety should probably be included with those listed as susceptible in New York State.

Pycnia.— The pycnia are the first fruiting bodies to appear in apple tissue attacked by the rust fungus. Masses of short-celled mycelium collect at certain points under the epidermis and form the flask-shaped pycnia of the usual rust type. Hyphal branches extend into the pycnial cavity and from the ends of these the pycnospores are abstricted (fig. 143).

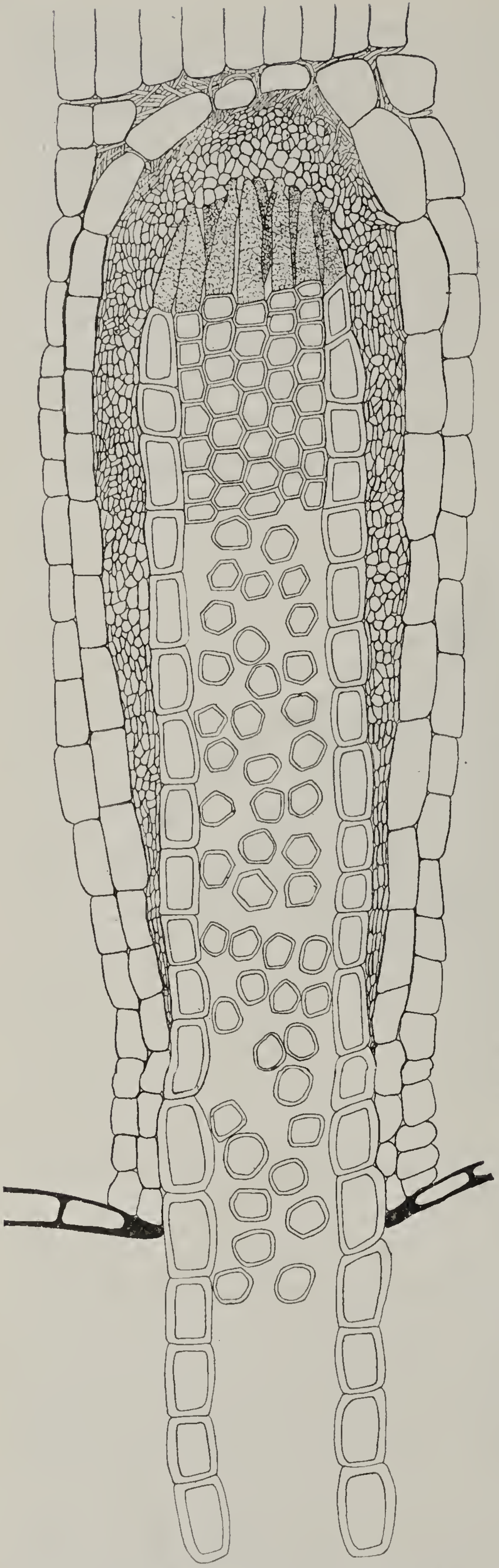

FIG. 144. AECIUM OF GYMNOSPORANGIUM GLOBOSUM IN CRATAEGUS LEAF

Aecia.— From two to four weeks after the pycnia become visible, depending largely on weather conditions, the aecia begin to break out on the lower surface of the leaves or from among the pycnia on stems or fruit. In New York State the aecia usually begin to break open about the first of August.

The tissues from which these fruiting bodies arise may be considerably hypertrophied, the spongy parenchyma especially being modified. Many septate strands of mycelium collect beneath the surface in the diseased area and from these the aecia are finally developed. The aecia are formed entirely within the host, but as they mature they break through the inclosing tissue, the peridium soon dehisces, and the spores are then scattered.

The aecia in all cases are composed of the inclosing pseudoparenchyma, the fertile spore-bearing stalks, and the aeciospores surrounded by the single layer of peridial cells (fig. 144). The aecia spores are binucleate and measure 16 to 24 μ by 21 to 31 μ. The spore wall varies in color from yellow to brown. When dehiscence occurs the peridium splits longitudinally between practically each row of cells. The ends of the cells remain attached, forming long strands which are one or more cells wide by several cells long. The individual cells are comparatively long and narrow, measuring 10 to 16 μ by 65 to 100 μ; they become much recurved when moist. The side walls are sparsely rugose with ridges extending the entire distance across. The aeciospores drop out of the aecia as they mature, and are carried by the wind to cedar trees where they initiate the telial stage.

Germination of aeciospores.— Many investigators have experienced great difficulty in germinating aeciospores. Heald (1909) states that he succeeded in germinating them previous to the first of October, after which time only one or two per cent germinated. Reed and Crabill (1915) found it impossible to germinate them except for an occasional germ tube, which seemed to be in a very weakened condition. Numerous trials made by the writer indicate that only a small proportion of these spores are capable of germination.

TABLE 2. RESULTS OF AECIOSPORE GERMINATION TESTS OF GYMNOSPORANGIUM JUNIPERI-VIRGINIANAE IN 1915

Number of slides	Date	Cultural solution	Temperature	Method	Percentage of germination
5	August 5......	0.2 per cent cane sugar and cedar leaf	24° C....	Spores on dry slide, culture solution added	1
1	August 5......	0.2 per cent cane sugar	24° C....	Spores on dry slide, culture solution added	75
1	August 5......	0.2 per cent cane sugar	24° C....	Spores on dry slide, culture solution added	25
3	August 5......	0.2 per cent cane sugar	24° C....	Spores on dry slide, culture solution added	0
5	August 5......	Tap water......	24° C....	Spores on dry slide, culture solution added	1
2	August 5......	0.2 per cent cane sugar	24° C....	Spores shaken on slide, culture solution sprayed in fine droplets on slide	0
5	August 5......	0.2 per cent cane sugar	24° C....	Spores shaken on slide, small drop of solution added	0
5	August 5......	0.2 per cent cane sugar	24° C....	Large drop of solution placed on slide, spores allowed to fall on solution	2 spores on each slide
2	September 29	Tap water......	22° C....	Suspension of spores	0
1	September 29	Tap water......	23° C....	Suspension of spores	0
1	September 29	Tap water......	26° C....	Suspension of spores	0
4	September 29	Tap water......	15° C....	Suspension of spores	0
2	August 28.....	Tap water......	23° C....	Spores shaken on dry slide, then placed in moist chamber	0

The method used in this work was practically the same as that recorded for the germination of teliospores. Water and a cane-sugar solution were used as culture media, to which, on various occasions, cedar leaves were added. In some cases the spores were shaken directly on the slide in order to obtain only mature spores, while in other preparations the aecia were placed on the slide and crushed, thus liberating all the spores present. The quantity of culture solution was varied, and in some cases the spores were first placed on the slide and the culture media was then added, while in other cases the spores were allowed to fall onto the surface of the culture solution.

The results of these experiments are recorded in table 2. Apparently a small proportion of aeciospores germinate under artificial conditions. Some of the spores used in the experiments were obtained from naturally infected and others from artificially infected leaves. The presence of cedar leaves in the culture media did not influence the germination of the spores.

Other germination tests were made with spores used for inoculating cedar trees, but only a few spores germinated. Hanging-drop mounts were employed in some cases not recorded, but these yielded no better results.

THE DISEASE CAUSED BY GYMNOSPORANGIUM GLOBOSUM

The disease caused by the fungus *Gymnosporangium globosum* is commonly known as *cedar rust*, *Crataegus rust*, or *pear rust*, depending on the stage referred to. The pathogene is native to North America and was first studied carefully by Farlow (1880). It is widely distributed throughout the eastern section of the United States, where it causes a rust of various species of Crataegus. The disease is of little economic importance, although on rare occasions the fungus attacks pears and quinces (Stewart, 1910).

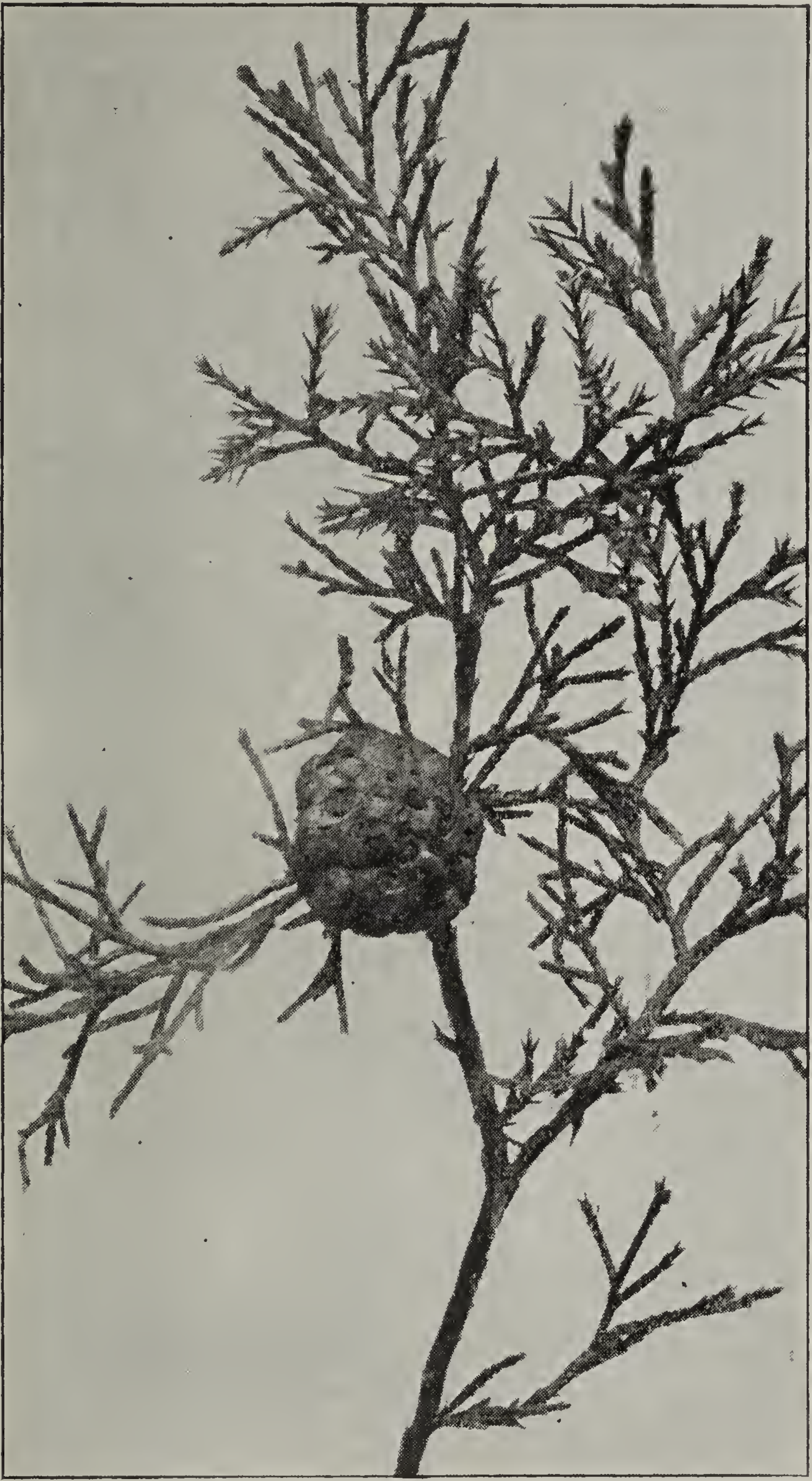

FIG. 145. CEDAR APPLE CAUSED BY GYMNOSPORANGIUM GLOBOSUM. WINTER CONDITION

SYMPTOMS

On cedar

The galls produced by this species are similar in appearance to those caused by *G. Juniperi-virginianae.* The gall produced by *G. globosum*, as the name would indicate, is usually globose in shape and is not so large as the gall caused by *G. Juniperi-virginianae.* The surface of the young gall in early autumn is smooth except for the shreds of the old leaf which cling to it. It approaches mahogany red in color, in contrast to the greenish brown of the *G. Juniperi-virginianae* gall. Instead of the pit-like depressions on the surface, the galls produced by *G. globosum* have small elevated areas, or mounds (fig. 145). From these raised areas the telial horns appear in the following spring.

The telial horns are wedged-shaped and are chestnut brown in color (fig. 146). Scars of the horns of former seasons are often apparent between the horns on old galls. When the warm spring rains occur, the protrusions gelatinize and enlarge to about double their normal size (fig. 147). These horns dry and drop off at the end of the fruiting season, but the galls may continue to live and bear spores for several seasons. The old galls turn brown and become roughened on the surface due to the scars of the telial horns.

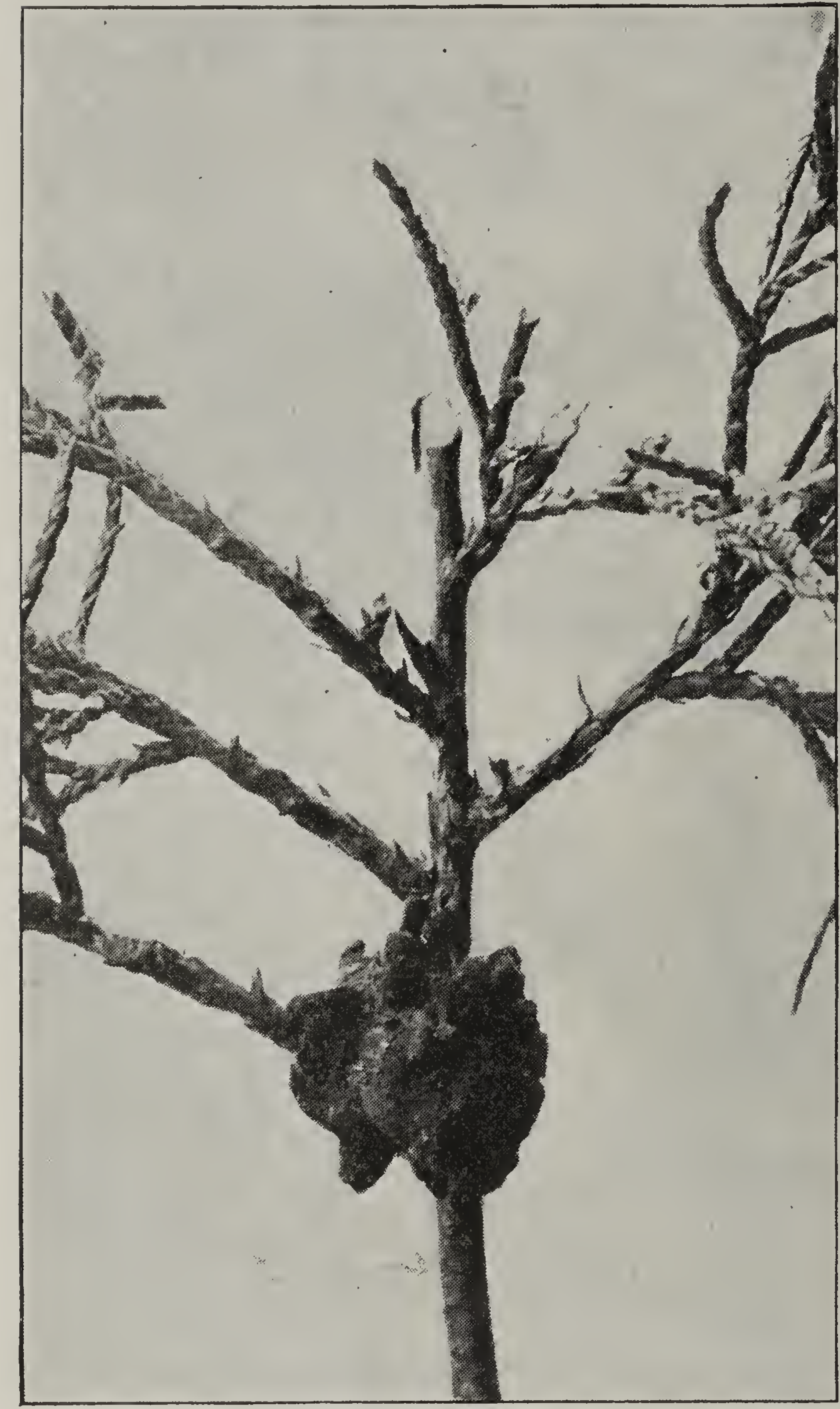

FIG. 146. GALL CAUSED BY GYMNOSPORANGIUM GLOBOSUM
The typical telial horns are shown prior to gelatinization

On quince

A yellow spot, such as characterizes the lesions caused by *G. Juniperi-virginianae* on the apple leaf, is formed by *G. globosum* on quince foliage. The pycnia and the aecia are likewise formed on the upper and the lower surface of the leaf, respectively. To all external appearances the symptoms are the same as those described for *G. Juniperi-virginianae* on apple foliage.

On pear

Stewart (1910) states that infected spots on the upper surface of pear leaves are dark brown or nearly black in color, with a conspicuous red border. Spots on the under surface are of the same dark color but have no red border. Aecia are produced in the largest lesions and also on the infected leaf petioles. In many cases the rust spots are arranged in two irregular rows, one on each side of the midrib, giving the appearance of infection having occurred before the leaves were unfolded. In 1910 Stewart observed that infected fruits were still clinging to the trees on June 15, although they were usually less than half the normal size. The

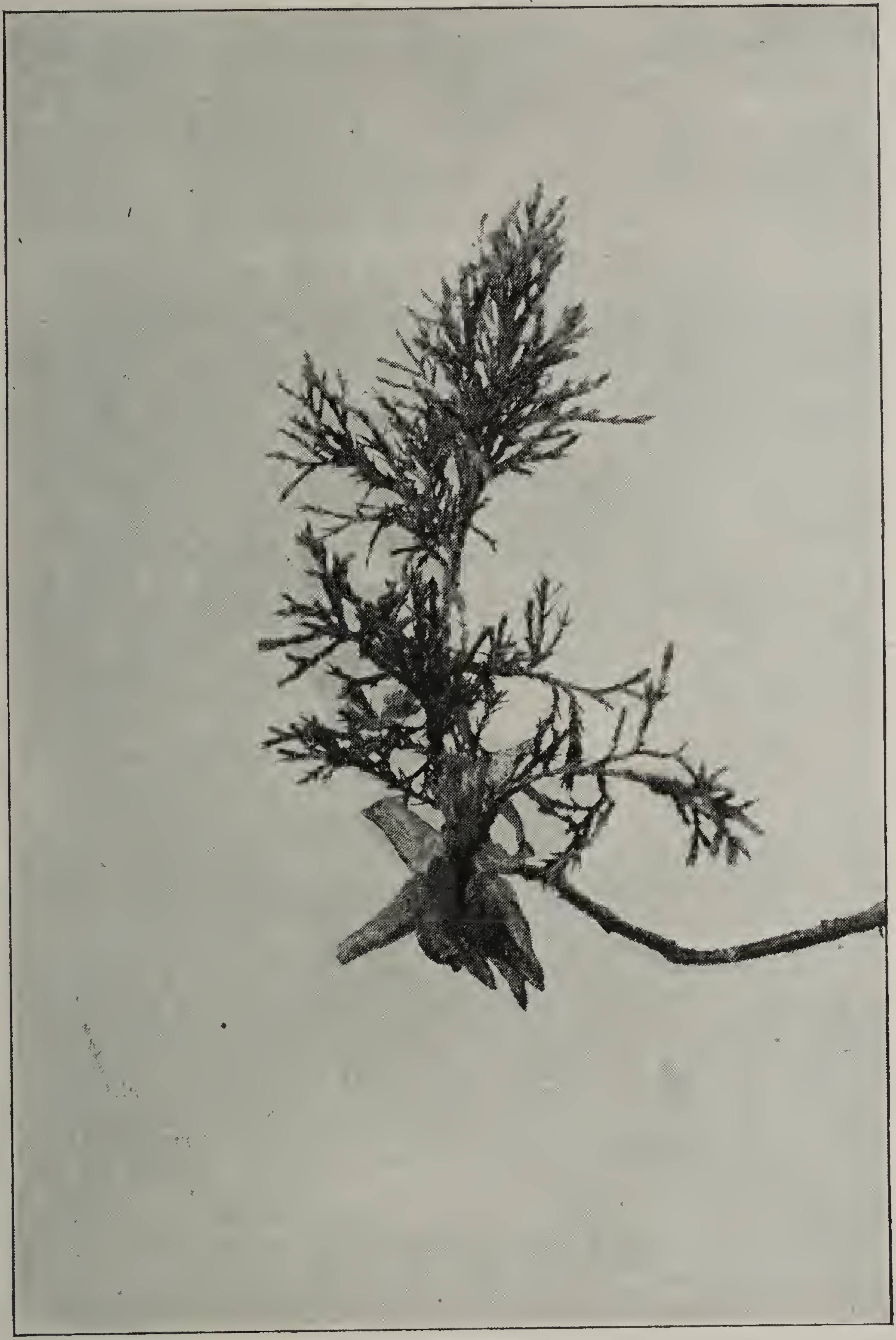

FIG. 147. TELIAL HORNS OF GYMNOSPORANGIUM GLOBOSUM FULLY GELATINIZED

fruit is often deformed and bears a circular, flattened, black lesion devoid of aecia near its base. Aecia are produced rarely.

On Crataegus

The lesion produced by *G. globosum* on Crataegus leaves is almost identical with the rust lesions on apple foliage. The red border about the margin of the spot is not so common, however, and the aecia are rarely arranged in the form of a circle (fig. 148).

The twigs of Crataegus are not commonly affected by this rust, but an occasional twig infection has been observed. The lesion is yellow, similar to that on the leaf, but practically no swelling of the twig is apparent. Pycnia are produced in this discolored area, followed later by aecia (fig. 149).

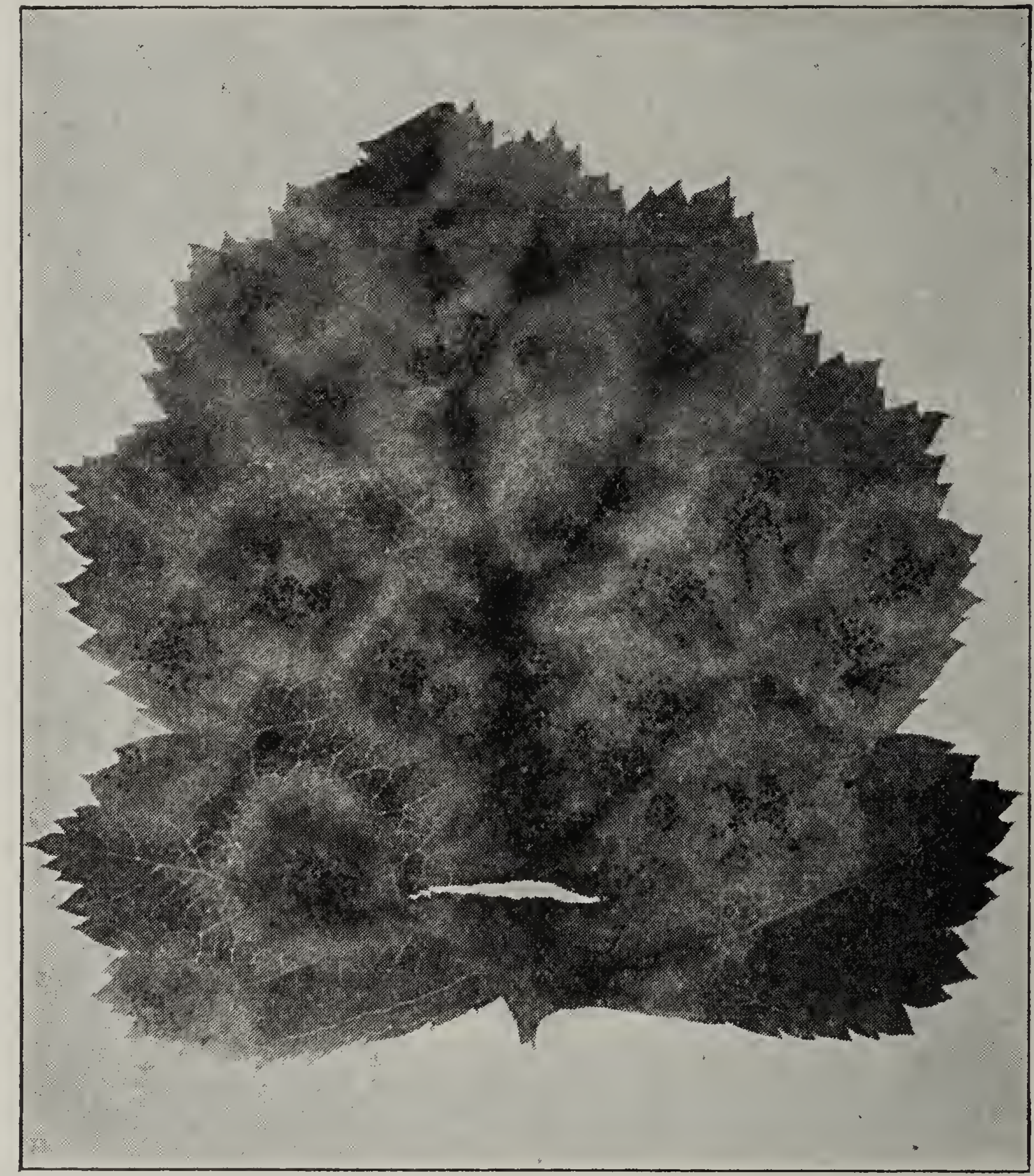

FIG. 148. CRATAEGUS LEAF ARTIFICIALLY INOCULATED WITH GYMNOSPORANGIUM GLOBOSUM
The groups of pycnia are apparent in the lesions

Infected fruits have been found, but these are not common. Here again a yellow spot is formed but little or no hypertrophy results. The pycnia and the aecia follow in the same lesion.

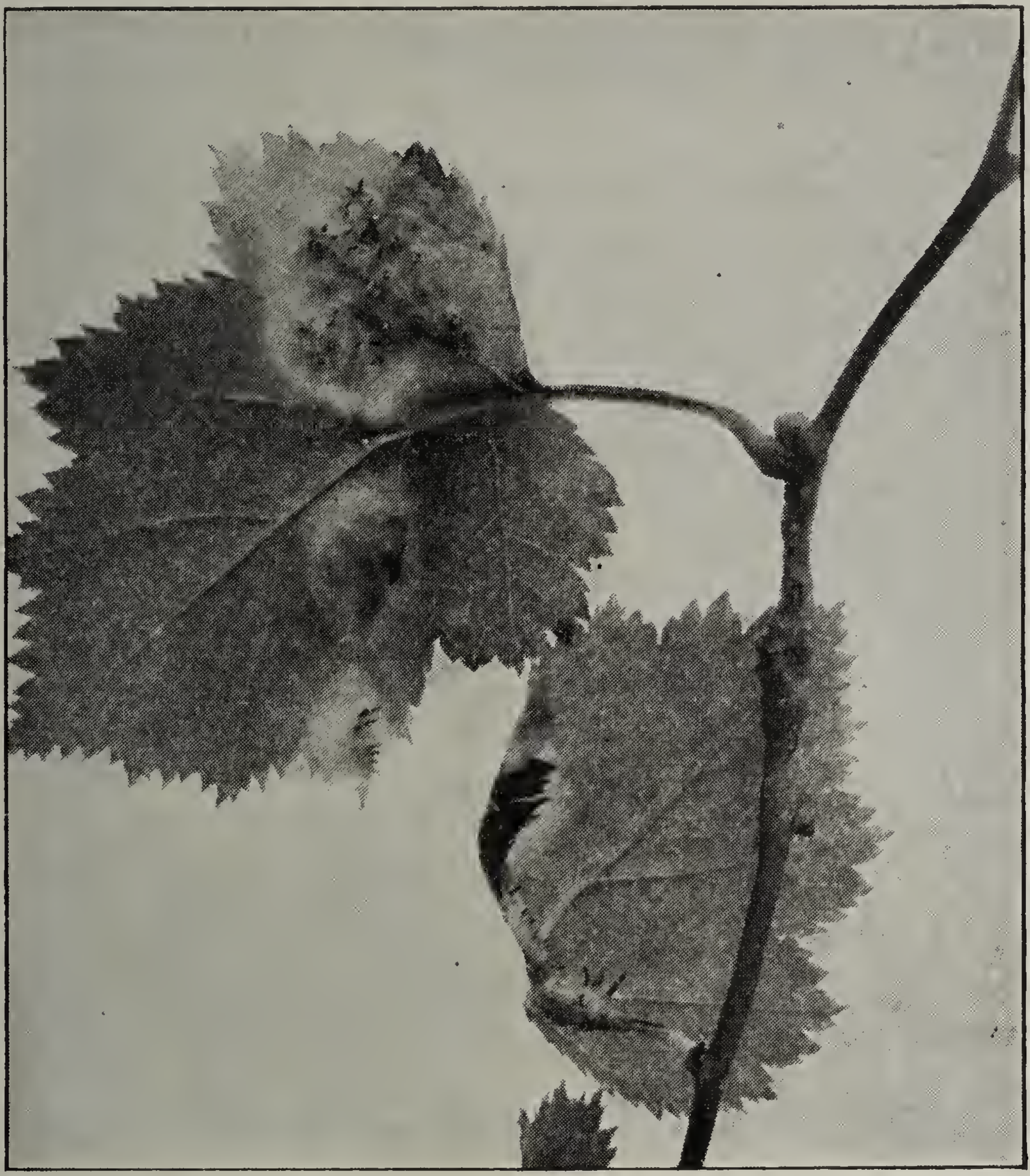

FIG. 149. AECIA OF GYMNOSPORANGIUM GLOBOSUM
The aecia are developing from the under surface of Crataegus leaves. The stem and the leaf petiole are also affected

ETIOLOGY

Nomenclature

The fungus now known as *G. globosum* was first named by Farlow in 1880. He gave it the name *G. fuscum* var. *globosum*, but later (Farlow, 1880) changed the name to *G. globosum*.

Life history

The details of the life cycle of this species are almost identical with those of *G. Juniperi-virginianae*. The aeciospores of the two species mature at approximately the same time. The time of infection of the cedar has not been determined, but it is presumably during the period when the aeciospores are being dispersed.

Rust-infected Crataegus leaves were collected on September 26, 1914, and exposed to the weather in a wire screen. At this time aeciospores taken from these leaves failed to germinate. Subsequent tests were made and germination was obtained until December 15, but all attempts to germinate these spores after this date failed.

Since aeciospores will germinate during and even later than the time of their dispersal, the writer sees no reason for assuming that infection does not take place until the following spring, as Reed and Crabill assume for *G. Juniperi-virginianae*. Although the penetration of the germ tube has never been observed, there is but little doubt that it enters the stomata. The mycelium develops within the cedar leaf for a period of from ten to twelve months before any sign of infection becomes apparent.

Telial stage

Development of telial horns.— The mycelium of this species is practically identical with that of *G. Juniperi-virginianae* and there is almost a complete absence of haustoria in the young galls. The telial horns are developed from a stromatic layer in the same manner as are those of *G. Juniperi-virginianae*. They begin to develop in the autumn but it is not until early the next spring that they become far enough advanced to penetrate the surface of the gall.

In the spring of 1915 the epidermis over the papillae had begun to break open on March 29, while at that time no evidence of this breaking could be found on the galls of *G. Juniperi-virginianae*. The telial horns were apparent on April 10. No growth in plant life was evident at that time and there was still considerable ice and snow on the ground. Spores capable of germination were present in these tentacles on April 15.

The telial horns continue to increase in size so that when gelatinization first takes place they may be from 1.5 to 3 millimeters thick by from 2 to 5 millimeters broad at the base and from 6 to 12 millimeters high. The number of horns on a gall varies from one to one hundred or more. They are distributed on the gall unevenly and are chestnut brown in color. Instead of standing singly they may coalesce and form a continuous band around the gall. The horns of *G. Juniperi-virginianae* have never been seen to fuse in this way.

The first gelatinization period usually coincides with the first warm rain period after the horns are protruded, and the number of times this process may occur during a season varies greatly. In 1914 the horns gelatinized four times and fell off on May 20, while in 1915 twelve such periods were recorded before the horns became dry on June 2.

The telial horns of this species may be more than double in size when swollen, and are then thinner in consistency than the jelly-like horns of

G. Juniperi-virginianae under similar conditions. After each protrusion the horns of the latter species dry down to their normal form with the exception of the tips. In the case of *G. globosum* drying occurs until the last gelatinization takes place, at which time the horns form a solid mass of thin, jelly-like substance over nearly the entire surface of the gall, and this substance intermingles with the adjoining leaves and twigs. When drying occurs this material clings to the leaves or twigs and is pulled loose from its attachments. The galls do not die as do those of the other species, but live and fruit year after year.

The teliospores of *G. globosum* closely resemble those of *G. Juniperi-virginianae.* They are practically of the same width, from 15 to 21 μ, but are often somewhat shorter, ranging in length from 37 to 54 μ. There are also the same number of pores and these are similarly located. The spore stalks are cylindrical in form. Teliospore germination is similar to that of *G. Juniperi-virginianae* (fig. 150).

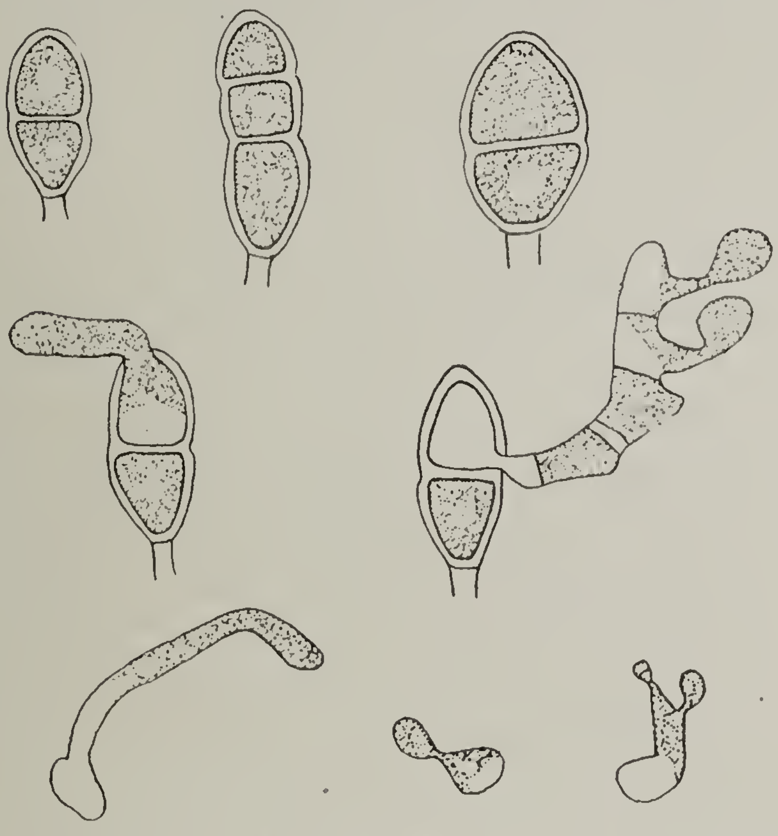

FIG. 150. VARIOUS TYPES OF TELIOSPORES OF GYMNOSPORANGIUM GLOBOSUM
Some of the teliospores and basidiospores have germinated. × 350

Aecial stage

The pycnia and the aecia of *G. globosum* are similar to those of *G. Juniperi-virginianae*, the greatest difference being in their size. The size and shape of the peridial cells is somewhat different for the two species. The peridial cells of *G. globosum* are broadly lanceolate in face view and measure 15 to 23 μ by 60 to 90 μ, and are linear-rhomboid in side view, measuring from 13 to 19 μ thick. The outer wall is smooth and about 1.5 μ thick, while the inner and side walls are slightly thicker and are rugose with ridge-like papillae of varying lengths.

Aeciospore germination.— Most attempts to germinate the aeciospores of *G. globosum* have yielded negative results. On two occasions slight germination was obtained, as is shown in table 3.

Inoculation of cedar trees.— Following the methods described under *G. Juniperi-virginianae*, many attempts have been made during a period of three years to obtain infection of red cedar with *G. globosum*, but thus far no positive results have been obtained.

TABLE 3. RESULTS OF AECIOSPORE GERMINATION TESTS OF GYMNOSPORANGIUM GLOBOSUM IN 1915

Number of slides	Date	Cultural solution	Temperature	Method	Percentage of germination
2	September 29	Tap water......	22° C....	Suspension of spores	0
2	September 29	Tap water......	23° C....	Suspension of spores	0
3	September 29	Tap water......	15° C....	Suspension of spores	0
5	September 30	Tap water......	24° C....	Spores in test tube immersed in an ice-and-salt bath at −4° to −6° C. for 1 hour, then allowed to incubate in tap water at 24° C.	0
5	October 2	Tap water......	24° C....	Spores treated same as above but not frozen, then suspended in water and incubated at 24° C.	0
20	October 2.....	Tap water......	−4° to +28° C.	Suspension of spores	0
2	November 8. .	Tap water......	24° C....	Spores in suspension; taken from leaves exposed to the weather since Sept. 26, 1915	10
1	December 9. .	Tap water......	24° C....	Spores in suspension; taken from leaves exposed to the weather since Sept. 26, 1915	2 spores germinated (only a few spores were present in this mount)

THE DISEASE CAUSED BY GYMNOSPORANGIUM CLAVIPES

The rust fungus *Gymnosporangium clavipes* causes a disease of quince, Crataegus, and cedar, which is commonly known as *quince rust*, *Crataegus rust*, or *cedar rust*. The fungus is native to North America and was first studied in some detail by Farlow (1880). It is widely distributed in eastern and central United States but is of little economic importance except on the quince. The writer observed a severe outbreak of quince rust in western New York in the summer of 1912.

The chief source of loss from quince rust is due to the misshapen or stunted condition of the diseased fruit. Twig infections also are common and these result in the death of the shoots affected.

SYMPTOMS

On cedar

On cedar the lesions of *G. clavipes* are confined to the twigs, and are less conspicuous than those of the other two species herein described. This species forms no large pendent galls, and in the early stages, as well as in many of the later ones, there is no noticeable hypertrophy of the affected twigs (fig. 151). A fusiform swelling may often occur, however, producing roughened areas on the bark (fig. 152). The affected areas may vary from 1 to 30 centimeters or more in length, but it is difficult to detect the early stages of infection of cedar until the telial sori emerge in the spring from the diseased areas. The telial sori are small, hemispheric, and orange-brown in color, and may also occur on the young shoots among the leaves. They gelatinize in early spring, and, as is true of the two preceding species, they finally dry and fall off. The fungus continues to fruit from the canker year after year.

On quince

Although quince leaves are not commonly affected by *G. clavipes* in nature, infection has been produced artificially on several occasions. The veins alone are attacked and often become swollen to double their normal size. The swelling of these veins causes the leaves to curl. The lesions are not accompanied by a change in color, as is the case with infected areas of apple or Crataegus leaves and of quince leaves affected by *G. globosum*. Pycnia are produced in longitudinal rows along the affected veins, similar to those described for *G. globosum* on pear foliage, but no aecia have ever been found. The leaves are finally killed and soon fall after the aecia are produced on the stem below.

In the spring the terminal buds of quince shoots are often attacked, the growth of affected twigs is retarded, and an increase in diameter occurs. The foliage is stunted, as in the case of the rust on apples. Pycnia and characteristic aecia appear later. Affected twigs die at the end of the season. On diseased quince fruit the affected part is often much enlarged, and in this area pycnia and aecia develop in abundance.

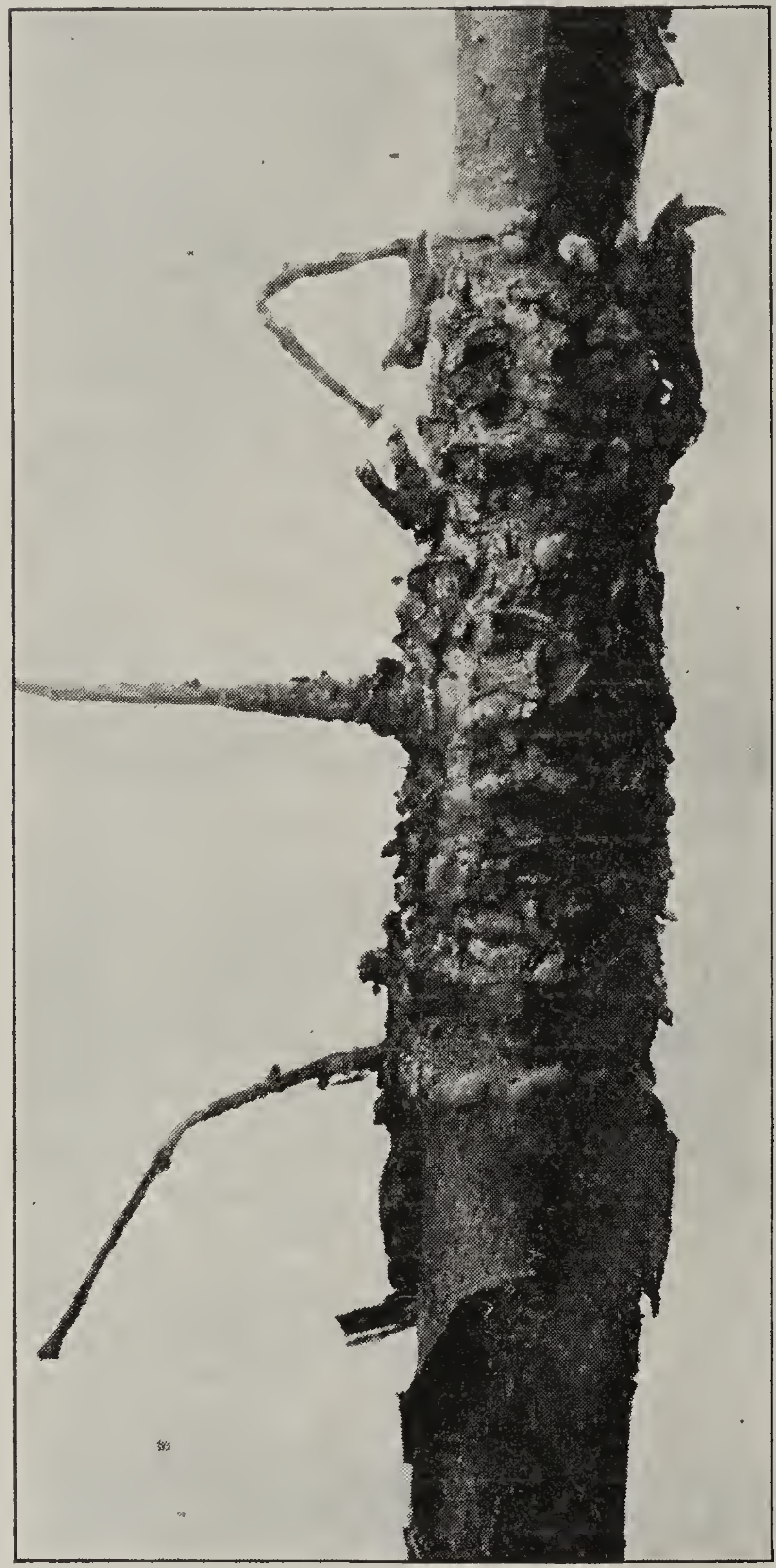

Fig. 151

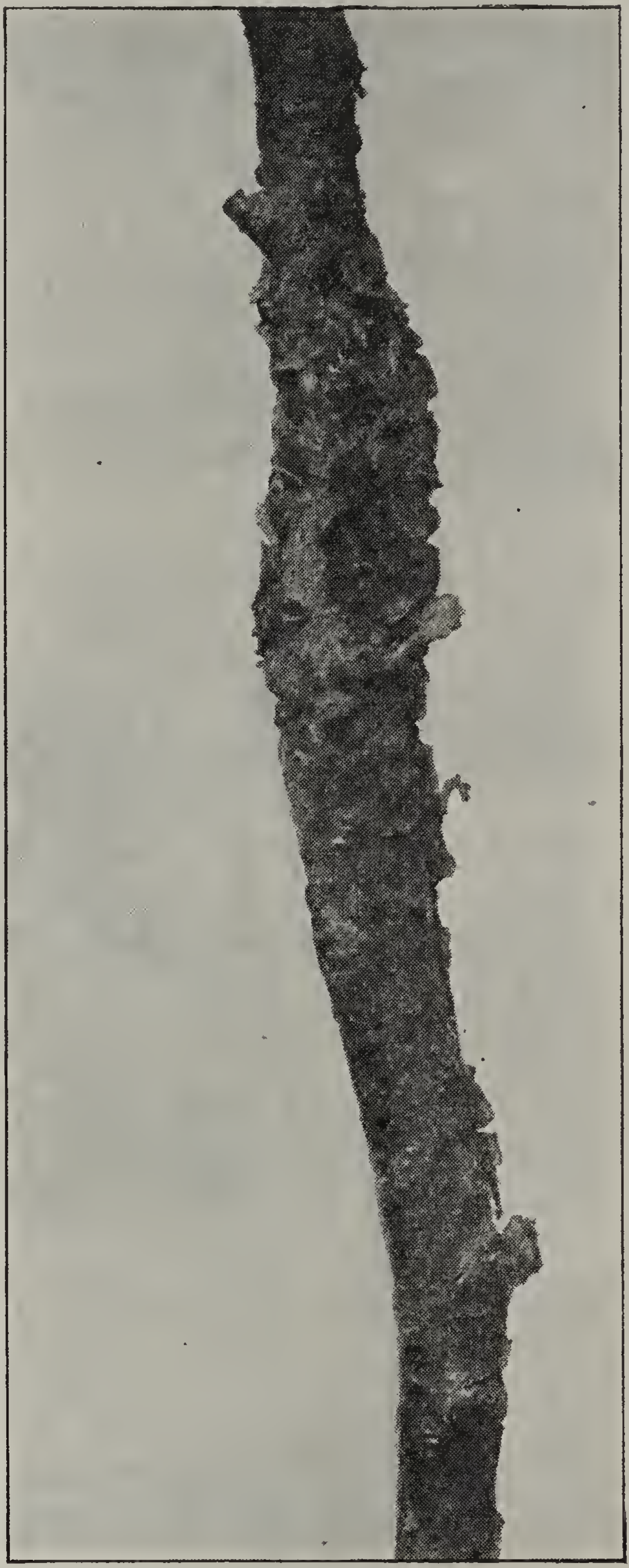

Fig. 152

FIG. 151. CANKER SHOWING TELIAL SORI OF GYMNOSPORANGIUM CLAVIPES

FIG. 152. CANKER CAUSED BY GYMNOSPORANGIUM CLAVIPES

The diseased area has a roughened appearance and is slightly enlarged as compared with the stem above and below

On Crataegus

The symptoms caused by *G. clavipes* on Crataegus are almost identical with those on quince. Although the leaves are rarely attacked, diseased leaves become curled and finally die without producing aecia (fig. 153).

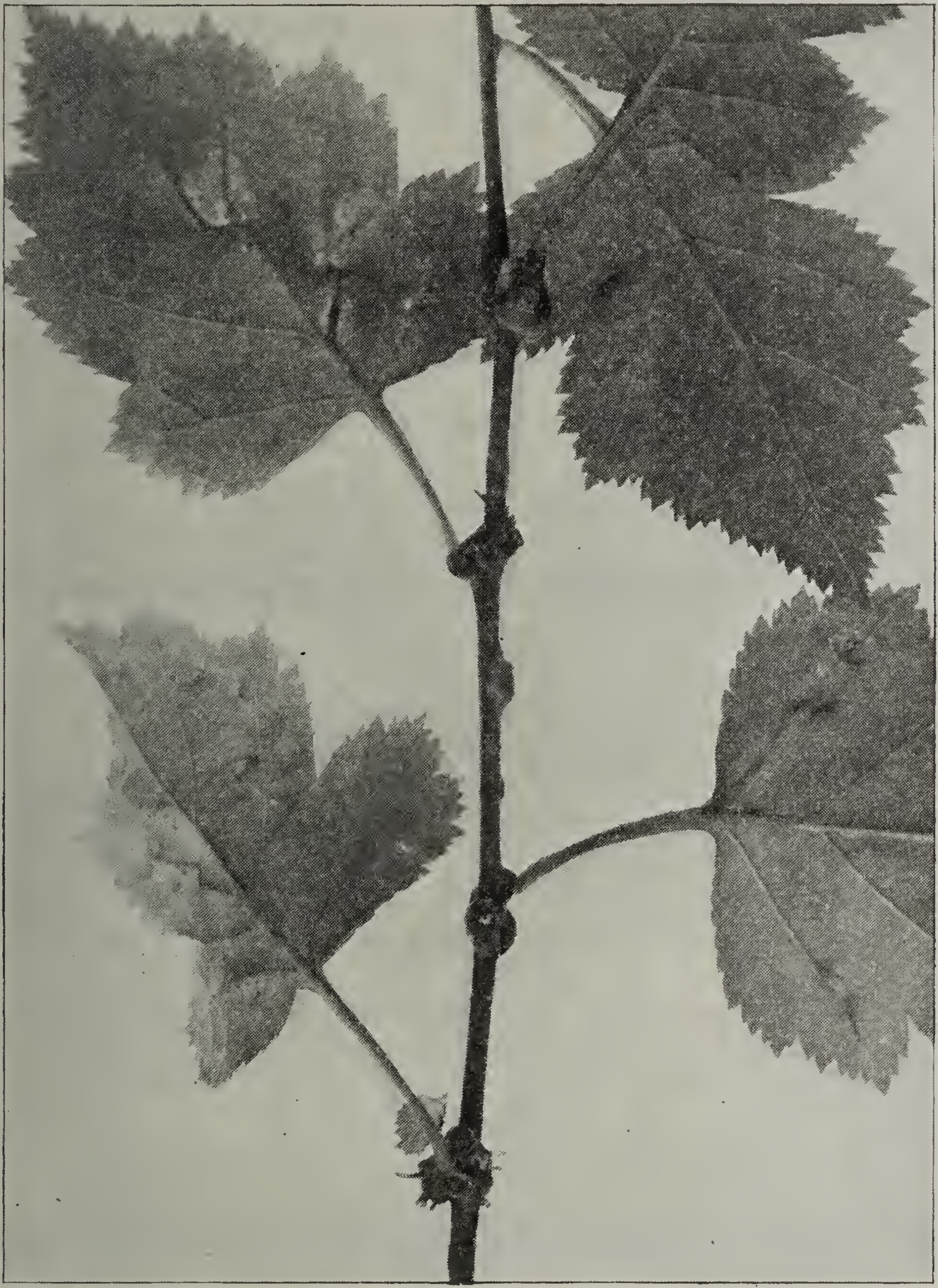

FIG. 153. GYMNOSPORANGIUM CLAVIPES AFFECTING LEAVES, PETIOLES, AND STEMS OF CRATAEGUS

These infections were produced by artificial inoculation

The stems, the leaf petioles, and the fruit are attacked commonly, and hypertrophy of the affected area occurs without change in color. Pycnia and aecia are produced in great quantities (fig. 154). The hypertrophied area is in some cases confined to only one side of the stem or the fruit.

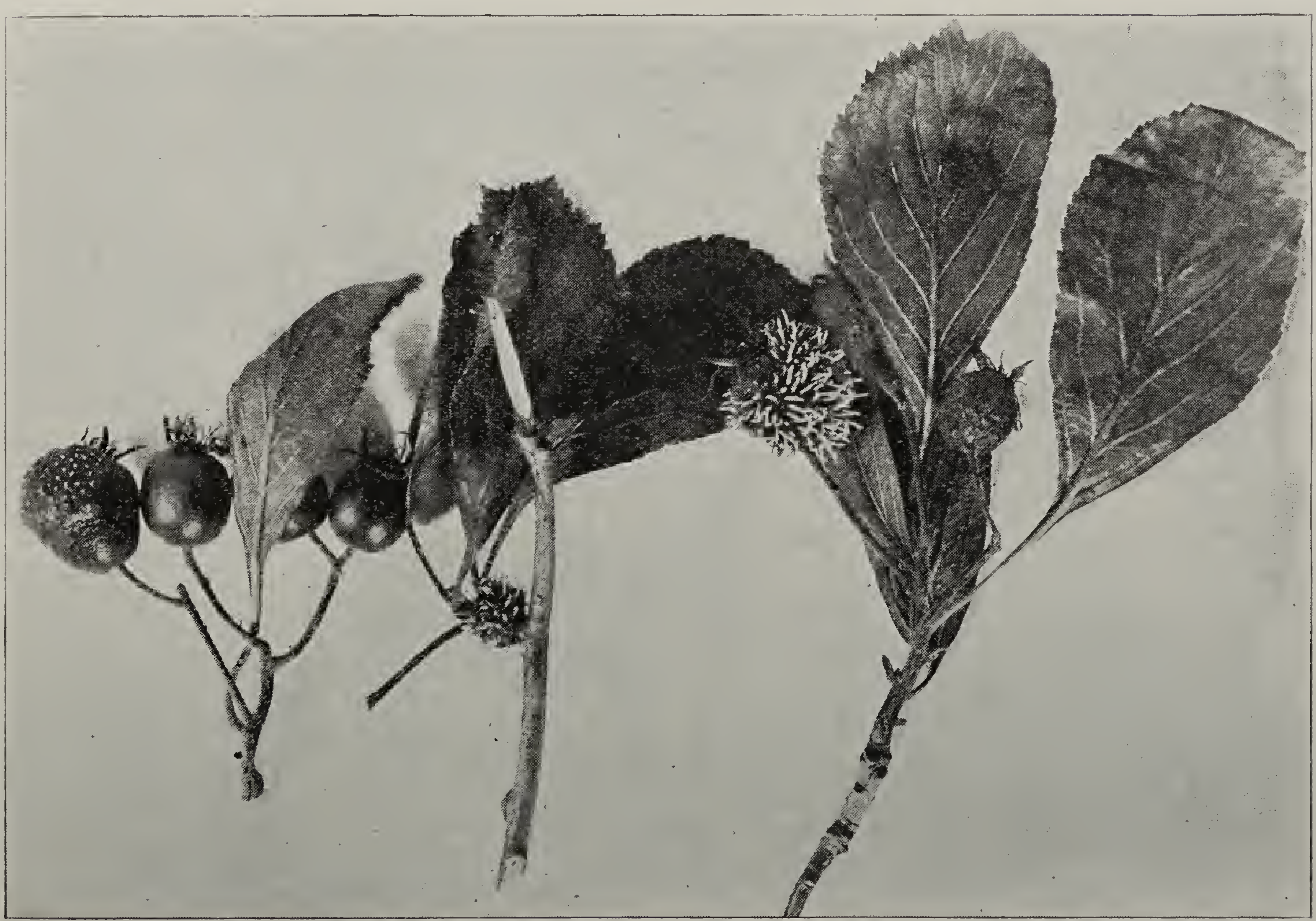

FIG. 154. FRUIT OF CRATAEGUS, SHOWING AECIA OF GYMNOSPORANGIUM CLAVIPES PROTRUDING FROM THE SURFACE

The thorns are often attacked and enlarge to double their normal size. The fungus may extend from an infected thorn into the twig at the base, and form a canker in which aecia may be produced in abundance late in the season. On October 12, 1915, a specimen was received from Romulus, New York, which bore fresh aecia in a canker that had developed at the base of a thorn.

ETIOLOGY

Nomenclature

This fungus was first named *Caeoma* (*Peridermium*) *germinale* by Schweinitz in 1832, and was given the name *G. clavipes* by Cook and Peck in 1873. Since the latter name is the first applied to the telial stage, it is the one now commonly accepted.

Life history

Only a small amount of literature has appeared which has a bearing on the origin and development of the telial stage of *G. clavipes*. This may be due, in part at least, to the fact that the disease causes little or no malformation on cedar.

Judging from analogy with other species, it is assumed that infection takes place in the late summer and autumn when the aeciospores are scattered; but no evidence of a diseased condition becomes apparent until the appearance of the telial sori. The sori develop on the two-years-old twigs and are apparently the result of infections of the previous year. This is in accordance with the process in the preceding species. The incubation period of this species is the same as that for *G. globosum* and *G. Juniperi-virginianae*; the infections that occurred during the summer and autumn of 1913 did not appear until the spring of 1915. The mycelium, which is similar to that of the other species, collects in masses beneath the corky exterior covering of the cedar twig, and from these stromata the spores arise and produce the telial horns (figs. 155 and 156).

Telial stage

Development of telial sori.— The first evidence of infection by *G. clavipes* is the appearance of the mound-like telial sori. These were first noticed in 1914 on April 22 and in 1915 on April 15. In 1914, however, the first basidiospores were formed in nature on May 5, while in 1915 some were produced on May 1. The telial sori appear on what seem to be normal and healthy twigs (fig. 157). They may be found emerging from the bark of branches of all sizes. In most cases little or no hypertrophy is noticeable, but in the older twigs slight fusiform swellings are developed.

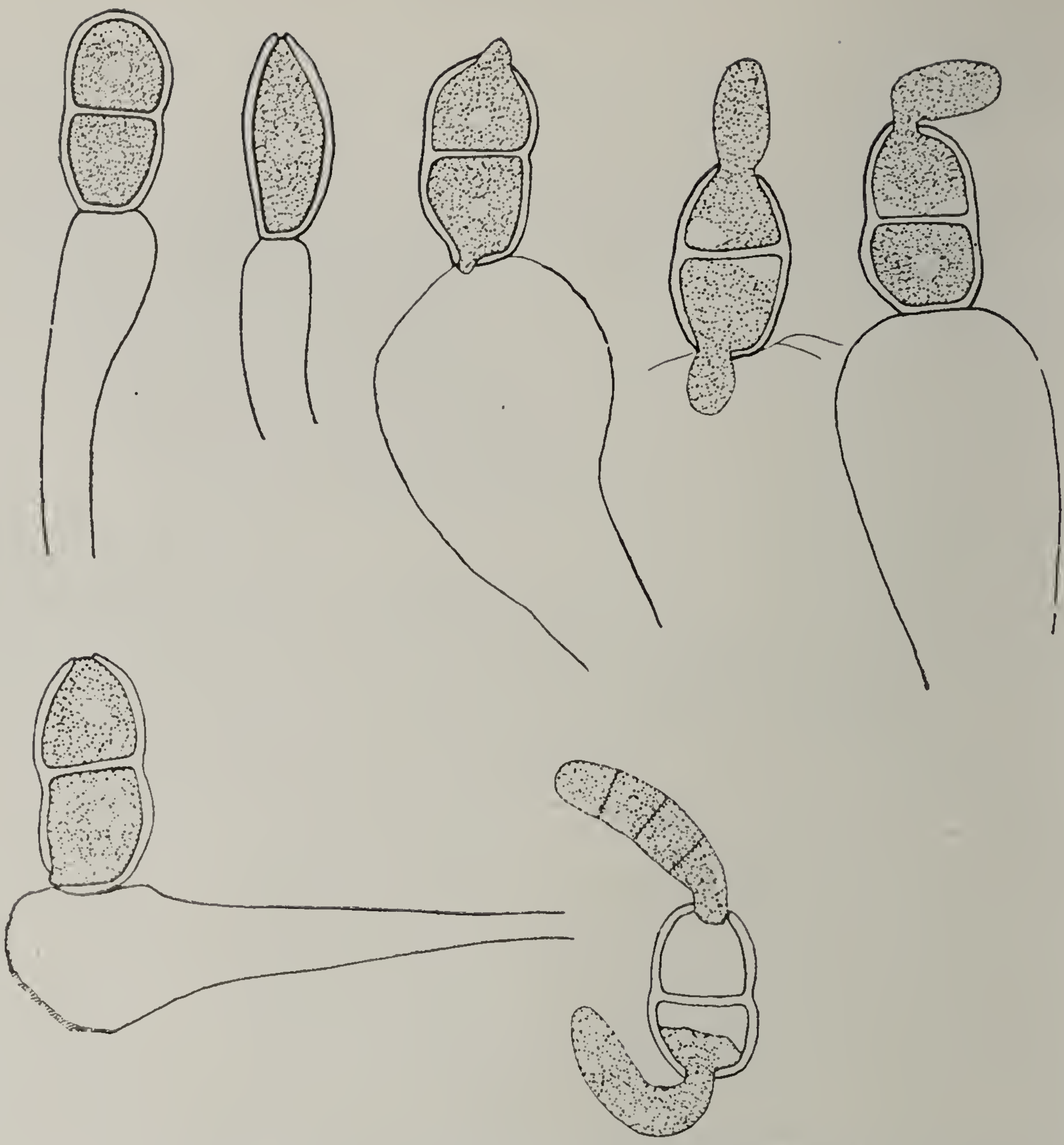

FIG. 155. TELIOSPORES AND TELIOSPORE GERMINATION OF GYMNOSPORANGIUM CLAVIPES

The spore stalk disappears at the time of germination of the lower cell. × 350

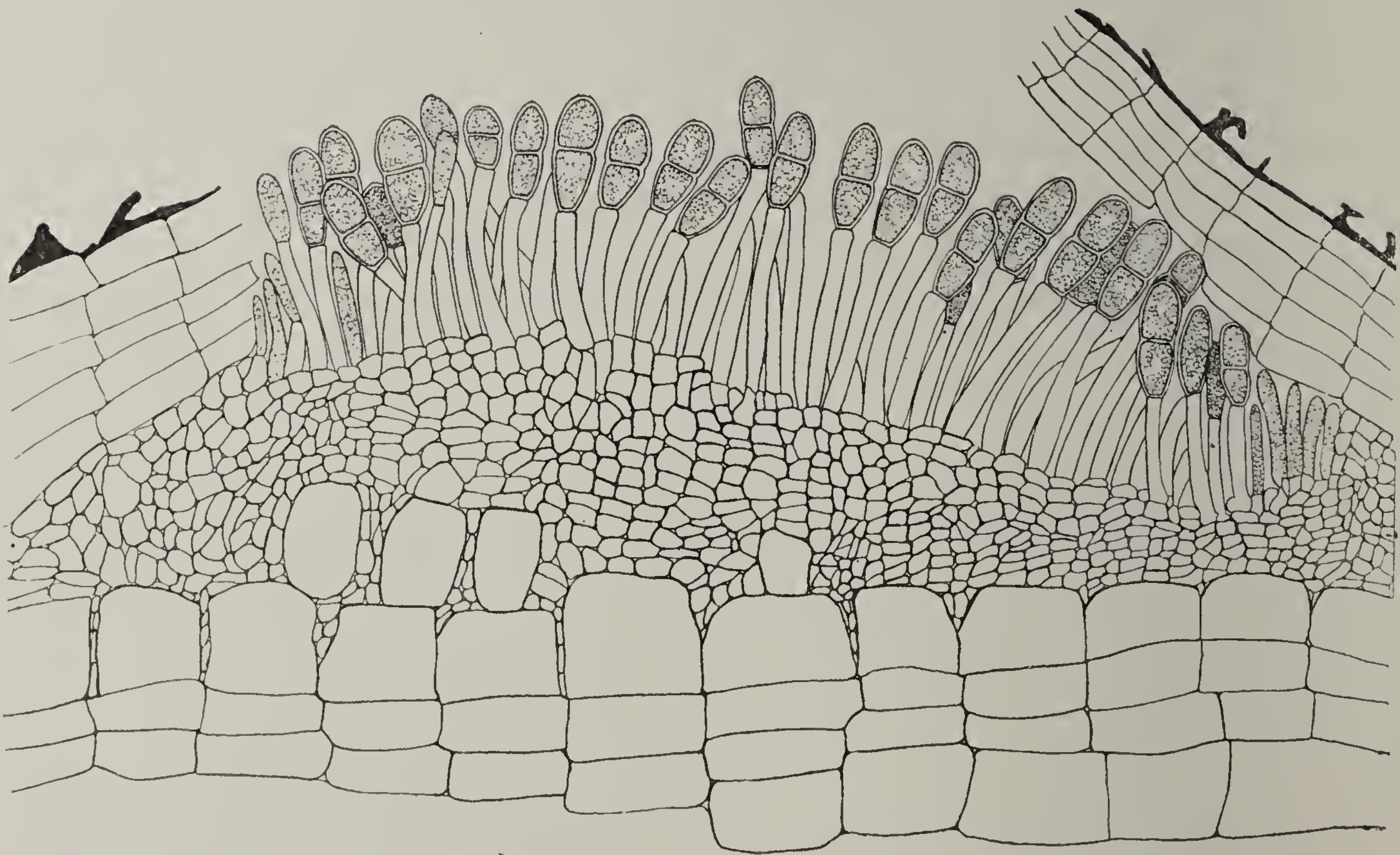

FIG. 156. A TELIAL SORUS OF GYMNOSPORANGIUM CLAVIPES

The sorus is just breaking through the cork tissue. × 220

The telial sori are decidedly different from the telial horns of *G. Juniperi-virginianae* and *G. globosum*. Instead of being long and of small diameter they are usually short and dome-shaped. These sori may be of various widths and they often coalesce and form a ring entirely around the twig. They are orange-brown when dry but become lighter-colored when gelatinized. In the latter condition they have a very soft, jelly-like consistency. After one or two gelatinizations the jelly-like substance spreads over the branches and the leaves, but later it becomes dry and drops off. The telial sori never recover their original shape. In 1914 there was a period of heavy precipitation from June 20 to June 22 and the sori did not regain their normal form after that time. In 1914 there were four gelatinization periods as compared with eleven in 1915. During several of these periods of gelatinization, few or no basidiospores were formed. Numerous cankers caused by this pathogene have been under observation since the spring of 1913, and each year telial sori have developed in the cankered areas. Undoubtedly the cankers were formed several years previous to 1913.

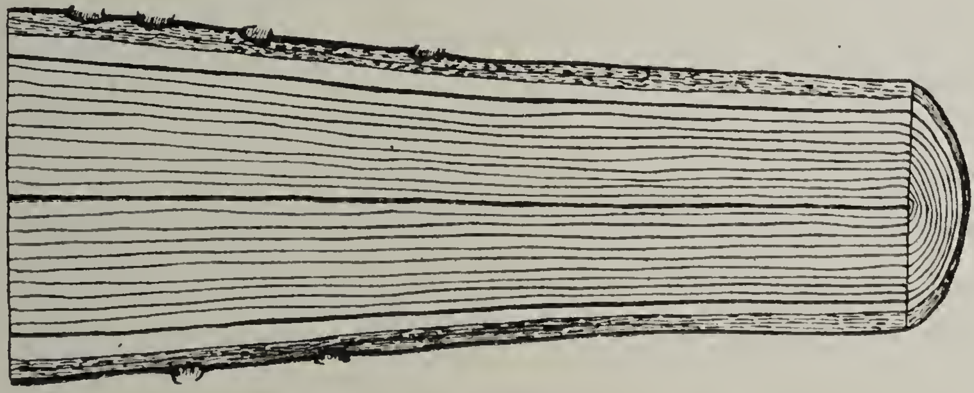

FIG. 157. DIAGRAMMATIC SECTION OF CEDAR TWIG AFFECTED WITH GYMNOSPORANGIUM CLAVIPES
The relative size and position of the telial sori are shown

Teliospore germination.— The teliospores of this species are capable of germinating at about the same time in the spring and under the same conditions as those of *G. globosum* and *G. Juniperi-virginianae.* The curve in figure 142 (page 523), and the discussion of methods and results on page 522, apply to this species also.

The spores of *G. clavipes* differ slightly from those of the other two species. They vary in length from 29 to 50 μ and in width from 17 to 25 μ. They may be slightly constricted at the septum, rounded or acute at the apex, and obtuse at the base. The wall is yellow and is from 1 to 2 μ thick, being slightly thickened at the apex. The pedicels may vary in diameter just below the spore from 7 to 50 μ, depending on the degree of swelling. Each cell has but one pore, the pore in the upper cell being in the apex and that in the lower cell being on one side near the base of the spore.

Spores of *G. clavipes* are peculiar in that often the germinating spores no longer have their spore stalks attached. It has been found that these stalks may be present if only the apical cell germinates, while, on the other hand, if both cells germinate the pedicels are never present or at least have not been seen. As soon as the basal cell begins to germinate, the side of the spore stalk nearest to the germ pore enlarges rapidly. The swelling continues until the wall of the stalk just below the germ pore finally disappears. Often before this stage has been reached the opposite side of the pedicel wall begins to disappear, so that soon only small remnants of the wall remain clinging to the spore. On certain slides on which spores were placed to germinate, absolute alcohol was added when the process of germination was only partially complete. The alcohol extracted the water, and the stalk returned to its normal shape and size. After the wall of the pedicel had become invisible it failed to return to view on the addition of alcohol. Apparently the lower promycelium develops at the base of the spore and thus displaces the pedicel. It is probable that the disappearance of the spore stalks when germination occurs accounts for the complete destruction of the telial sori as mentioned above. Numerous observations have been made to determine whether or not a similar phenomenon occurs in *G. globosum* and *G. Juniperi-virginianae*, but this has never been found to be the case. In these species the promycelium develops near the septum, so that it is not obstructed by the pedicel.

The disintegration of the pedicel in *G. clavipes* has been noticed also by certain other writers. Farlow (1880) states that when quickly swollen, especially by the absorption of reagents, the inner part of the pedicel expands more quickly than the outer part, so that the latter is ruptured just below the spore, leaving a hyaline ring surrounding the pedicel at the base of the spore. Farlow's explanation of this phenomenon seems logical so far as it goes, but it is not clear why this process takes place only when it accompanies the germination of the lower cell.

The methods of ejection and germination of the basidiospores of *G. clavipes* are identical with those described for *G. Juniperi-virginianae.*

Throughout a period of three years numerous attempts were made to produce infection with spores of *G. clavipes* on red cedar trees, but only negative results were obtained.

Aecial stage

The conditions influencing infection and the development of pycnia and aecia of *G. clavipes* are similar to those for the other two species. Both fruiting structures resemble closely those of *G. Juniperi-virginianae.* The pycnia, however, are about one-fourth larger. The peridium and the peridial cells, together with the size of the aeciospores, serve as the distinguishing features. The aecia are much broader than those of *G. globosum* and the aeciospores measure from 21 to 32 μ by from 24 to 39 μ.

The peridium of *G. clavipes* is white, while those of the other two species are slightly yellowish. The peridium splits longitudinally, in some cases to the base of the cup, but the strands may be several layers of cells in width. These strands may either stand erect or become more or less recurved at their extremities. Kern (1911:455) describes the peridial cells as follows:

> Peridial cells seen in both face and side views, polygonal-ovate or polygonal oblong in face view, 19–39 x 45–95 μ, rhomboid in side view, 25–40 μ thick, outer wall moderately thick, 3–5 μ, inner wall very thick, 13–23 μ, coarsely verrucose with loosely set, large, irregularly branched papillae, side walls verrucose on inner half similar to inner wall.

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A REVISION OF THE GENUS LYGUS AS IT OCCURS IN AMERICA NORTH OF MEXICO, WITH BIOLOGICAL DATA ON THE SPECIES FROM NEW YORK

HARRY H. KNIGHT

ITHACA, NEW YORK
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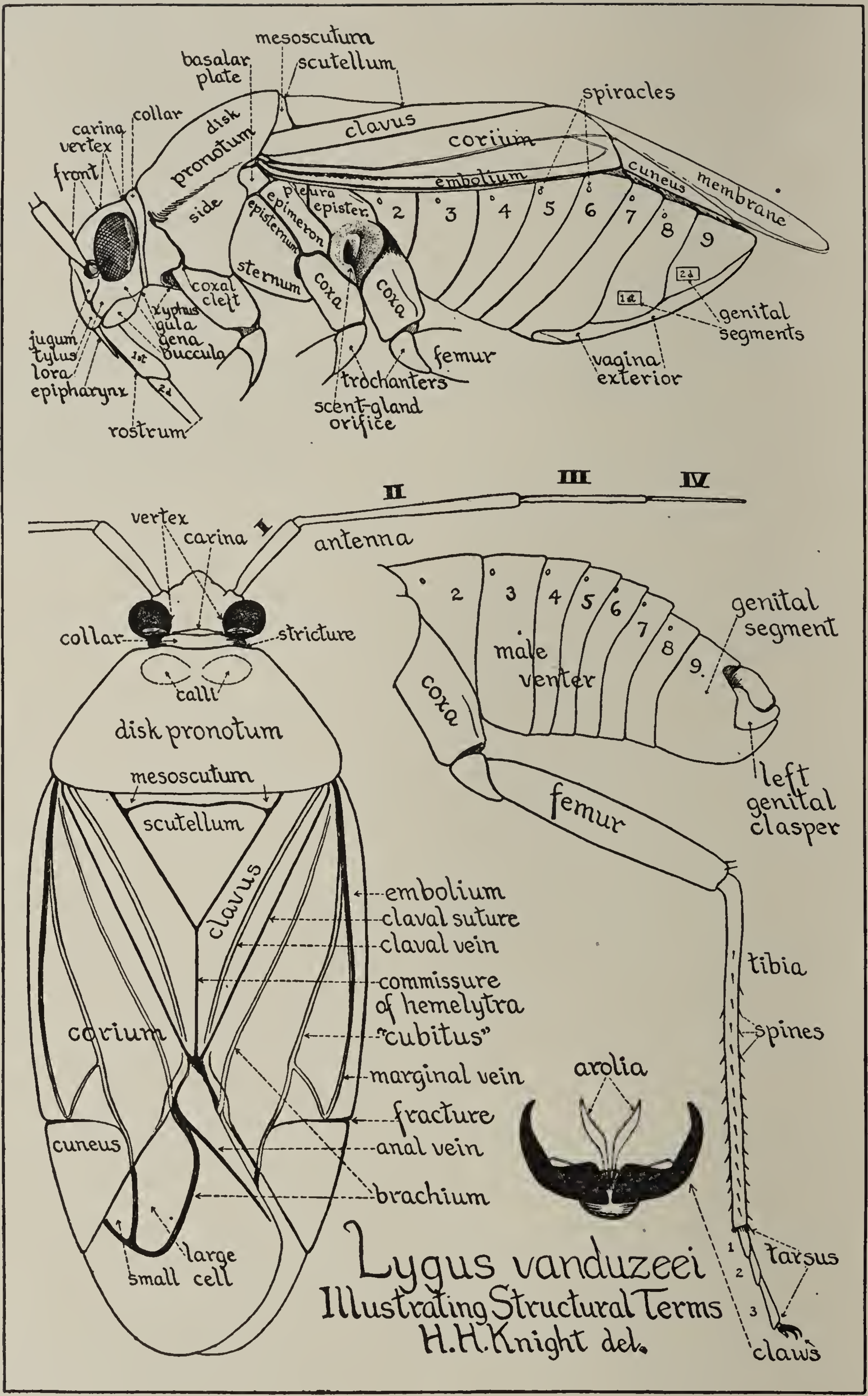

Lygus vanduzeei
Illustrating Structural Terms
H.H.Knight del.

A REVISION OF THE GENUS LYGUS AS IT OCCURS IN AMERICA NORTH OF MEXICO, WITH BIOLOGICAL DATA ON THE SPECIES FROM NEW YORK

Order, *Hemiptera* Family, *Miridae*

Harry H. Knight

The genus Lygus contains a large number of species which have been found very puzzling not only to the general entomologist but also to specialists in Hemiptera. Owing to the species that have developed as pests, there has been a great need among economic entomologists for a work that would enable them to determine the species accurately. The writer, realizing the necessity for a better knowledge of the group, has spent much time during the past three seasons accumulating life history data and at the same time working out characters by means of which the trained entomologist may determine the species.

The genus includes the well-known tarnished plant bug (*Lygus pratensis* Linn.), a cosmopolitan pest of long standing on a variety of plants of economic value. During the past five years two other species have become serious pests to pears and apples, and there is a strong probability that other forms already present on native wild vegetation may change their food habits and attack cultivated plants. Data are here given on twenty-eight species found in the State of New York, with nine species occurring in neighboring States which will doubtless soon be found within our borders. Food plants and other biological data are given for all but one of the species known to occur in this State. The present paper gives a much-needed systematic revision of the group; but the most important feature is that structural characters found in the male genital claspers have been worked out and shown to furnish a reliable criterion for recognition of the species.

The writer is indebted to Mr. E. P. Van Duzee, who very kindly sent for study from his collection all the forms of Lygus known to him; to the late Mr. O. Heidemann, of the United States National Museum, who made it possible for the writer to study the collections in the National Museum as well as his own private collection; to Mr. H. M. Parshley for sending considerable material which he assembled from the New England States; and to Dr. J. Chester Bradley for valuable criticism during the progress of the work.

GENUS **LYGUS** HAHN

The genus Lygus was founded by Hahn in 1831 to include nine species, of which *limbatus* Fallén was subsequently selected as the type. In common with other genera in the tribe Capsini, Lygus is characterized by having free erect arolia (pulvilli between the claws) with the apical half diverging (Plate XXIII). The following are the more essential characters of the genus:

Head nearly vertical, in length shorter than the height at base; vertex with a basal carina and before it a more or less triangular depressed area; vertex of the female usually slightly wider than in the male; front convex, smooth; tylus prominent, its base nearly on a line with the base of the antennae; juga, lorae, and bucculae prominent, clearly defined; eyes prominent, ovate when viewed from the side, the posterior margins nearly parallel with the base of the head; facial angle (when viewed from the side, the angle formed by the contour line of the tylus and the lower margin of the buccula) a right angle. Rostrum usually reaching to near the posterior margin of the hind coxa, shorter in a few species, but exceptionally long in *approximatus* and *convexicollis*. Antennae inserted slightly above the lower margin of the eye, linear; first segment the thickest; second segment usually slightly thicker at the apex than at the base; third and fourth segments shorter and becoming setaceous; finely pubescent; second segment slightly shorter and more slender in the female than in the male. Pronotum trapezoidal, collar formed by a narrow ring-like apical constriction extending over the sides and beneath; disk moderately convex, broader at the base than long, gently sloping at sides, and immarginate; calli usually apparent as smooth shining ovals; disk punctate except between the calli and on the subelevated part just before. Scutellum moderately elevated, mesoscutum more or less exposed. Hemelytra surpassing the tip of the abdomen, slightly longer in the male; cuneus rather strongly deflected, the fracture extending inward to a point opposite the middle of the end of the corium; membrane biareolate. Legs rather long, hind femora moderately incrassate; tibiae armed with spines, in length equal to the thickness of the tibia or longer. Upper surface and the abdomen clothed with fine pubescence. Structure of the male genital claspers giving specific differences.

Lygus shows affinities with Dichrooscytus on the one hand and with Neoborus and Lygidea on the other. Dichrooscytus differs in the shape of the head, the type of pubescence, and the aciculate punctuation on the pronotum; Neoborus differs in being punctate between the calli and just before; Lygidea has a differently shaped head, and the pronotum has coarse, deep, rugose punctuation on the disk.

METHODS OF STUDY

The terminology used in this work is as follows:

Length of the insect is the measurement taken between the tip of the tylus and the apex of the membrane; *width* is taken at the widest point on the hemelytra.

Head: *Width* is measured from the dorsal aspect and taken across the eyes at the widest point; *vertex* is the space between the inner margins of the eyes at the top of the head; *length* is measured laterally, taken at right angles to the base of the head, a point determined by the base of the gula and the hind margin of the eye; *height* is the measurement between the base of the gula and the top of either the eye or the carina, whichever projects the higher.

Antenna: *Length* of the first segment is taken from the point of greatest constriction just above the basal knob, to the apex; the length of all the segments is taken when each is horizontal and extended straight to its full length.

Pronotum: *Length* is the greatest measurement that can be obtained along the median line, between the front margin of the collar and the hind margin of the disk, taken when the disk is turned as nearly horizontal as possible; *width at base* is taken across the basal angles of the disk; *width at anterior angles* is taken at the point where the front margins of the disk turn sharply inward to the constriction.

The genital claspers are shown in the present paper to be excellent characters for separating the species. In the *pratensis* group the differences in the male claspers are in some cases not so easily used as other characters, thus showing a close group relationship. In the remaining groups (II to VI) the genital claspers show a wide range of variation, thus affording very distinct specific and subgeneric characters.

For purposes of study and in order to make drawings of the genital claspers, the specimens may be soaked for a few minutes in a watch glass filled with 85-per-cent alcohol. When sufficiently soft the tip of the abdomen may be picked off with the aid of two needles, working beneath the binocular microscope. The claspers may then be carefully separated from the attaching muscles and mounted for study. To make drawings the claspers should be removed to a dish coated with a mixture of paraffin and beeswax. This material makes an excellent surface for the manipulation of the claspers and for holding them in any desired position. Later the claspers may be removed on the point of a needle and attached with shellac to a triangle mounted on a pin beneath the insect.

The genital claspers figured in the present paper are all drawn to the same scale and turned to the same relative position for purposes of comparison. In a few cases extra views are presented in order to show unusual structures to better advantage, and in such cases an explanation is given. The figures were made by working with an eyepiece micrometer in the binocular microscope, which proved more satisfactory than using the camera lucida.

GROUPS OF LYGUS

The species of Lygus are here divided into six groups, based entirely on the structure of the male genital claspers. The species within each group are arranged to show relationship as far as possible. Fifty-four species and thirteen varieties are included, of which thirty-four species and eleven varieties are described as new. The records for distribution show only the material studied by the writer, and therefore he assumes responsibility for determinations.

The *communis* group appears to be confined almost entirely to eastern North America, with records of two species having been found as far west as Colorado. On the other hand, the *pratensis* group has comparatively few species in the East but a multiplicity of forms in the western United States. Several species in the *communis* group, having a definite food plant, are found on that plant only in situations where conditions of humidity and sunshine are favorable to the particular species. In rearing nymphs it was observed that they die easily when subjected to high temperatures and undue dryness. This may offer some explanation why the species representing this group are not found in the Western States. The nymphs of species in the *communis* group are certainly more delicate than the nymphs of *pratensis* and its allies.

The six groups into which the genus is divided in this study are differentiated as follows:

Group I (*pratensis* group): Left clasper without a prong at the middle (at the posterior extremity of the lateral aspect), but with a large serrate dorsal lobe at the base; right clasper with a small claw at the apex, curving ventrad or caudad, in length less than the greatest width of the clasper. (?Subgenus *Lygus* Hahn, Reuter):

pratensis var. *oblineatus* Say (p. 564)
pratensis var. *rubidus* n. var. (p. 565)
vanduzeei n. sp. (p. 565)
vanduzeei var. *rubroclarus* n. var. (p. 567)
convexicollis Reuter (p. 568)
convexicollis var. *coloratus* n. var. (p. 569)
humeralis n. sp. (p. 570)
columbiensis n. sp. (p. 571)
superiorensis n. sp. (p. 572)
atriflavus n. sp. (p. 572)
elisus Van Duzee (p. 574)
elisus var. *viridiscutatus* n. var. (p. 575)
elisus var. *hesperus* n. var. (p. 575)
plagiatus Uhler (p. 576)
striatus n. sp. (p. 578)
nigropallidus n. sp. (p. 579)
aeratus n. sp. (p. 580)
bradleyi n. sp. (p. 581)
nubilus Van Duzee (p. 582)
ultranubilus n. sp. (p. 583)
nubilatus n. sp. (p. 584)
nubilosus n. sp. (p. 585)
distinguendus Reuter (p. 586)
distinguendus var. *tahoensis* n. var. (p. 587)
(?) *robustus* Uhler (p. 588)

Group II (*campestris* group): Left clasper without a prong at the middle, but the lateral lobe less basal and not serrate, outline of the lateral aspect different from that of *pratensis* group; right clasper with a short claw, or absent (*rubicundus*); composed of more heterogeneous forms:

rubicundus Fallén (subgenus *Agnocoris* Reuter) (p. 589)
rubicundus var. *winnipegensis* n. var. (p. 591)
sallei Stål (p. 591)
campestris Linnaeus (subgenus *Orthops* Fieber) (p. 592)
distinctus n. sp. (p. 594)
pabulinus Linnaeus (subgenus *Lygocoris* Reuter) (p. 595)

Group III: Left clasper without a prong at the middle, the lateral lobe not serrate; right clasper with a relatively large thick prong at the apex; one species of doubtful generic position placed here:

approximatus Stål (p. 597)

Group IV: Left clasper without a prong or lobe at the base, the apex of the internal prong bifurcate; right clasper much reduced, with only a minute hook or claw:

olivaceus Reuter (p. 599)
olivaceus var. *viridiusculus* n. var. (p. 600)
fasciatus Reuter (p. 601)

Group V: Left clasper with complex lobe at the base, without a prong at the middle; right clasper greatly reduced, with a minute claw at the apex; only one aberrant form placed here:

apicalis Fieber (p. 601)

Group VI (*communis* group): Left clasper with a prong at the middle; right clasper with a hook or prong projecting mesad, its length as great as or greater than the thickest part of the clasper; composed of a large number of homogeneous forms. (Subgenus *Neolygus*, new subgenus; type, *Lygus communis* Knight):

fagi n. sp. (p. 603)
invitus Say (p. 604)
atritylus n. sp. (p. 606)
confusus n. sp. (p. 606)
alni n. sp. (p. 607)
geneseensis n. sp. (p. 609)
viburni n. sp. (p. 609)
parshleyi n. sp. (p. 611)
parshleyi var. *shermani* n. var. (p. 612)
inconspicuus n. sp. (p. 612)
tiliae n. sp. (p. 613)
caryae n. sp. (p. 615)
caryae var. *subfuscus* n. var. (p. 616)
atrinotatus n. sp. (p. 617)

vitticollis Reuter (p. 618)
neglectus n. sp. (p. 619)
communis Knight (p. 620)
communis var. *novascotiensis* Knight (p. 623)
univittatus n. sp. (p. 623)
quercalbae n. sp. (p. 624)
semivittatus n. sp. (p. 626)
omnivagus n. sp. (p. 627)
johnsoni n. sp. (p. 629)
belfragii Reuter (p. 630)
clavigenitalis n. sp. (p. 632)
hirticulus Van Duzee (p. 633)
canadensis n. sp. (p. 634)
canadensis var. *binotatus* n. var. (p. 635)
ostryae n. sp. (p. 635)
laureae n. sp. (p. 636)
(?) *carolinae* Reuter (p. 638)

The types of the new species, unless otherwise designated, will eventually be found in the Cornell University collection.

DESCRIPTIONS OF SPECIES AND VARIETIES

Lygus pratensis Linnaeus

1746 *Cimex griseus* Linnaeus
Fauna Svec., p. 208.
1758 *Cimex pratensis* Linnaeus
Syst. nat., 10th ed., p. 448.
1763 *Cimex umbellatarum* Scopoli
Ent. carniol., p. 133.
1778 (?) *Cimex rubecula* Goeze
Ent. Beitr. **2**:279.
1794 *Lygaeus pratensis* Fabricius
Ent. syst. **4**:171.
1804 (?) *Lygaeus viridulus* Panzer
Schaeff. icon., p. 120.
1804 *Miris pratensis* Latreille
Hist. nat. **12**:221.
1805 *Lygaeus umbellatarum* Panzer (see Reuter, 1888)
Faunæ ins. Germ., no. 93.
1805 *Coreus* (?) *lineolaris* Palisot de Beauvais
Ins. réc. Afr. et Amér., p. 187.
1807 *Lygaeus campestris* Fallén (not Linnaeus)
Mon. cim. Svec., p. 83.
1828 *Phytocoris campestris* Zetterstedt (not Linnaeus)
Fauna ins. lapp., p. 273.
1828 *Phytocoris pratensis* Zetterstedt
Fauna ins. lapp., p. 289.
1829 *Phytocoris campestris* Fallén (not Linnaeus)
Hemip. Svec., p. 91.
1831 *Capsus oblineatus* Say
Heterop. Hemip. N. Amer., p. 340 (Le Conte ed.).
1831 *Phytocoris campestris* Hahn (not Linnaeus)
Wanz. Ins. **1**:218.
1835 *Capsus gemellatus* Herrich-Schaeffer
Wanz. Ins. **3**:81.

1837 *Phytocoris artemisiae* Schilling
Uebers. Arbeit. u. Veränd. Schles. Gesell. vaterl. Kultur in 1836, p. 83.
1837 *Phytocoris adspersus* Schilling
Uebers. Arbeit. u. Veränd. Schles. Gesell. vaterl. Kultur in 1836, p. 83.
1840 *Phytocoris campestris* Blanchard (not Linnaeus)
Hist. nat. ins. **3**:138.
1840 *Phytocoris punctata* Zetterstedt
Ins. lapp., p. 273.
1841 *Phytocoris lineolaris* Harris
Ins. inj. veg., p. 161.
1843 *Capsus pratensis* Meyer-Dür
Verzeich. Schweiz Rhyn., p. 99.
1845 *Phytocoris campestris* Kolenati (not Linnaeus)
Melet. ent. **2**:118.
1845 *Phytocoris alpina* Kolenati
Melet. ent. **2**:120.
1848 *Capsus punctatus* Sahlberg
Mon. geoc. Fenn., p. 110.
1848 *Capsus campestris* Sahlberg (not Linnaeus)
Mon. geoc. Fenn., p. 111.
1855 *Capsus (Deraeocoris) gemellatus* Kirschbaum
Rhyn. Wiesb. **10**:273.
1855 *Capsus (Deraeocoris) pratensis* Kirschbaum
Rhyn. Wiesb. **10**:273.
1855 *Capsus (Deraeocoris) campestris* Kirschbaum (not Linnaeus)
Ryhn. Wiesb. **10**:273.
1858 *Deraeocoris campestris* Stål (not Linnaeus)
Ent. Zeit. [Stettin] **19**:186.
1858 *Deraeocoris pratensis* Stål
Ent. Zeit. [Stettin] **19**:186.
1861 *Lygus pratensis* Fieber
Eur. Hemip., p. 273.
1861 *Lygus campestris* Fieber (not Linnaeus)
Eur. Hemip., p. 273.
1862 *Phytocoris linearis* Uhler
Flint ed. Harris, Ins. inj. veg., p. 200 (footnote).
1871 *Capsus linearis* LeBaron
Nox. ins. Ill., 1st rept., p. 62.
1872 *Capsus flavonotatus* Provancher
Nat. Can. **4**:103.
1872 *Lygus lineolaris* Uhler
U. S. Geol. Surv. Terr., Montana, Prelim. rept., p. 413.
1872 *Lygus diffusus* Uhler
U. S. Geol. Surv. Terr., Wyoming, Prelim. rept., p. 471. (Never described.)
1872 *Lygus redimitus* Uhler
U. S. Geol. Surv. Terr., Wyoming, Prelim. rept., p. 471. (Never described.)
1875 *Lygus pratensis* var. *typicus* Reuter
Hemip. gymn. Scand. et Fenn., p. 71.
1886 *Lygus flavonotatus* Provancher
Petite faune ent. Can. **3**:119, 120.
1888 *Lygus rutilans* Horváth
Rev. d'ent. **7**:181.
1900 *Lygus campestris* var. *fuscorubra* Strobl
Naturw. Ver. Steiermark, Mitt. **36**:188.
1906 *Lygus pratensis* var. *discrepans* Reuter
Mus. Zool. St.-Petersb., Ann. **10**:39.
1912 *Lygus pratensis* var. *pubescens* Reuter [=*campestris* Fallén, name preoccupied]
Hemip. miscellen, p. 37.

Reuter (1896, 1906, 1912) has recognized the following varieties from the Old World:

Lygus pratensis punctatus Zetterstedt
L. pratensis rutilans Horváth
L. pratensis gemellatus Herrich-Schaeffer
L. pratensis typicus Reuter
L. pratensis pubescens Reuter
L. pratensis discrepans Reuter

The commonest form of *pratensis* from the eastern United States is *oblineatus* Say, which compares very favorably with the variety *punctatus* Zetterstedt. The writer has studied European specimens of the varieties *typicus* Reuter, *gemellatus* Herrich-Schaeffer, and *pubescens* Reuter (determined by Reuter), and finds nothing from the United States that could be called the same. From a study of the literature the writer is likewise unable to recognize any forms that will agree with the varieties *rutilans* Horváth and *discrepans* Reuter.

Lygus pratensis var. **oblineatus** Say

Ovate, shining; yellowish brown with more or less blackish marking, or reddish brown and fuscous; pronotum with yellowish and blackish rays; scutellum margined with blackish, leaving a Y- or heart-shaped area yellowish; hemelytra reddish brown or blackish, streaked with yellowish or gray.

♂. Length 4.9–5.5 mm. *Head*: width across eyes 1.11 mm., vertex .45 mm., length .51 mm., height at base .65 mm.; impunctate shining; carina nearly straight, indented just in front on vertex; yellowish brown or reddish to blackish, the darkest forms blackish on the tylus and the median line of the front with one or two shorter rays at each side. *Rostrum*, length 2.28 mm., reaching posterior margins of hind coxae, yellowish brown to reddish brown, apex blackish.

Antennae: segment I, length .51 mm.; II, 1.46 mm.; III, .88 mm.; IV, .74 mm.; yellowish brown to reddish brown, last two segments and apical one-third of second segment blackish; darkest forms entirely blackish with brownish only on middle third of segment II.

Pronotum: length 1.25 mm., width at base 2.17 mm., width at anterior angles 1.03 mm., collar .77 mm.; deeply and irregularly punctured, calli smooth and shining, delimited behind and between by an impressed line; yellowish brown to reddish brown with blackish; blackish on the calli with two spots or rays behind each callus, also blackish at basal angles of disk and in some cases extending as a ray along the side margins; yellowish or brownish between the blackish rays and narrowly along basal and side margins of disk; fine pale depressed pubescence. *Scutellum* dull yellowish or reddish brown in the pale forms, with two black dashes at middle of base and a brownish line at each side paralleling the margin; dark forms with the pale color reduced to a Y or even to three pale dashes; transversely rugose across the middle. *Sternum* dark reddish brown to blackish, paler on the sides; pleura reddish brown to blackish, margins and orifice paler.

Hemelytra: greatest width 2.5 mm.; coarsely and deeply punctate, heaviest on clavus; fine pale depressed pubescence; pale forms, yellowish brown to reddish brown, darker at apex of corium; dark forms, gray brown to blackish, paler on claval vein, brachium, cubitus, and embolium; cuneus translucent, dark brownish to reddish black bordering base and at apex. *Membrane* fuscous, paler in the middle; bordering the cuneus, the veins, and a marginal spot just beyond the apex of the cuneus, pale.

Legs: yellowish brown, reddish yellow, or blackish, the posterior femora twice annulated near apices with darker; dark forms with coxae and femora blackish, annulated with paler near apex of femora; tibiae with two blackish marks near base; tibial spines, tips of tibiae, and tarsi, brownish to blackish.

Venter: yellowish brown, reddish brown, or dark reddish to blackish, the sides with a longitudinal pale stripe; genital claspers (fig. 158) distinctive of the species; shape of claw on right clasper separates the species from its nearest relatives.

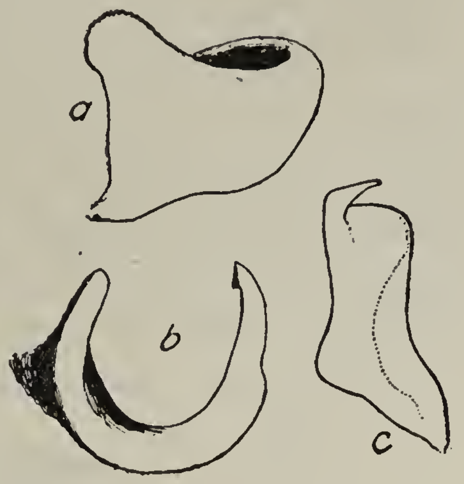

FIG. 158. LYGUS PRATENSIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

This is the commonest species in the eastern United States and is found everywhere frequenting many kinds of plants. It is a pest on nursery stock, ornamental plants, and cultivated crops. A full account of its life history, food habits, and economic status is given by Crosby and Leonard (1914), together with a very complete bibliography, containing 316 titles, dealing with the literature on this species.

Lygus pratensis var. **rubidus** new variety

Structurally not differing from *pratensis*, but bright ruby red in color.

♂. Length 5.5 mm., width 2.5 mm.; bright ruby red; pronotum with a small black spot behind each callus; antennal segments red, with apex of segment II, and all of segments III and IV, blackish; scutellum pale, marked with red at middle of base; cuneus margined with red, but pale translucent in the middle; orifice and a longitudinal stripe on sides of venter, paler; tibiae pale reddish, spines black; sternum beneath, and tips of tarsi, blackish.

Holotype: ♂ July 14, Eastport, Maine (H. M. Parshley).

This form is comparable to *vanduzeei* var. *rubroclarus*, both being produced apparently by the northern conditions and the high altitudes.

Lygus vanduzeei new species

1909 *Lygus convexicollis* Reuter
Bemerk. neark. Caps., p. 43.

Larger than *pratensis*, about the size of *convexicollis* but differing in color and pubescence; nearly glabrous, strongly shining, yellowish brown to rich brown with fuscous; genital claspers distinctive of the species.

♂. Length 7.1 mm. *Head*: width across eyes 1.25 mm., vertex .5 mm., length .6 mm., height at base .77 mm.; yellowish brown, eyes dark brown, impunctate and shining. *Rostrum*, length 2.93 mm., just attaining posterior margins of hind coxae, yellowish brown, apex blackish.

Antennae: segment I, length .85 mm., reddish brown to piceous; II, 2.22 mm., bright reddish brown, apex blackish; III, 1.31 mm., blackish, narrowly pale at base; IV, 1 mm., fuscous; all the segments finely pubescent.

Pronotum: Length 1.7 mm., width at base 2.82 mm., width at anterior angles 1.2 mm., collar .91 mm.; nearly glabrous, strongly shining, punctures deep and irregularly placed, otherwise very similar to *pratensis* in structure; a small black spot behind each callus, usually two in the darkest specimens; basal angles with a black spot just inside the narrow pale margins, in the darkest specimens extending along lateral margins of disk; a small black spot just above the coxal cleft; dark specimens having dark brown rays behind the black spots on disk and with paler between. *Scutellum* transversely rugose and sparsely punctate, finely pubescent; yellowish brown, apex and a dash each side at base paler. *Sternum* opaque, yellowish brown, frequently fuscous beneath; pleura marked with fuscous in dark specimens; orifice pale.

Hemelytra: greatest width 3.3 mm.; strongly shining, pubescence minute, nearly glabrous; punctures coarse and deep, somewhat crowded, most prominent on the clavus; rich dark brown, darker on clavus and on apex of corium; claval vein and cubitus pale; embolium yellowish translucent except at apex, the narrow exterior edge of embolium blackish for its full length; cuneus yellowish translucent, dark brownish to blackish at base and on extreme apex. *Membrane* fuliginous, a pale spot in the center and one each side just beyond apex of cuneus; veins at apices of cells and bordering apex of cuneus also pale.

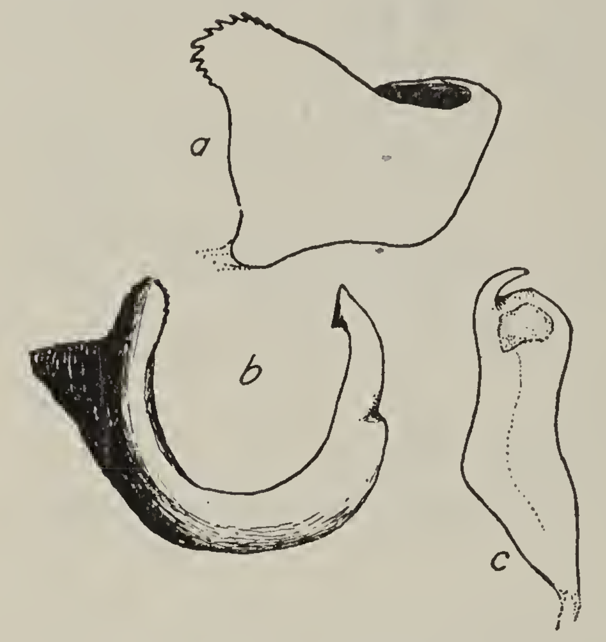

FIG. 159. LYGUS VANDUZEEI, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Legs: yellowish brown, apical half of posterior femora dark brownish to blackish, annulated near the apices with two pale rings; tibiae more greenish yellow, apices and spines dark brownish, a dark spot on the base and in some cases extending down the tibia as a stripe; tarsi dark brownish, tips blackish.

Venter: yellowish brown, a dark brownish longitudinal stripe each side, in some specimens brownish beneath thus forming a pale stripe beneath the dark lateral one; fine pale pubescence; genital claspers (fig. 159) typical of the group, but the shape of the claw on the right clasper and of the internal arm on the left distinguishes the species.

♀. Very similar to the male in size and coloration.

The species is named after E. P. Van Duzee, who was the first to point out the fact that this eastern form of Lygus is not the same as Reuter's *convexicollis* from California.

Reuter (1909) records *convexicollis* from New York and Pennsylvania after a study of specimens sent by Mr. Van Duzee and by O. Heidemann. This record should apply to *vanduzeei*. The true *convexicollis* is apparently restricted to the Pacific Coast States.

The species breeds on *Solidago canadensis* and possibly on other kinds of goldenrod found growing in rich moist soil. Many of the adults hibernate, as does *pratensis*, and come forth on the tender goldenrod plants during May. Several specimens may often be picked from a few unfolding heads of the tender plants, where they congregate for feeding soon after coming out of hibernation. The eggs are doubtless stuck in the tender stems of goldenrod, where the nymphs appear and feed during July. In New York most of the adults mature by the middle of August, and then continue to feed on the host plant until the cool September nights make them seek hibernation quarters. There is apparently only one brood each year, while *pratensis* has a second and even a partial third brood.

Holotype: ♂ June 22, 1916, Portage, New York (H. H. Knight).

Allotype: with the type.

Paratypes: 2 ♂ May 24, 8 ♂ ♀ June 21, 37 ♂ ♀ June 22, 35 ♂ ♀ June 27, ♂ 3 ♀ August 9, Portage, ♀ June 7, ♂ June 26, ♀ June 28, 2 ♀ July 5, ♀ July 6, 4 ♂ ♀ July 27, ♀ August 1, Batavia, 47 ♂ ♀ July 4–5, Four Mile, 3 ♂ 3 ♀ June 25, Wyoming, 4 ♀ July 27, McLean, 6 ♂ ♀ August 22, Whiteface Mountain, New York; all collected by the writer. ♂ 2 ♀ July 28, Lake George, New York (A. K. Fisher). 2 ♂ 2 ♀ June 12, 2 ♀ July 1, ♀ July 23, Hamburg, ♀ August 10, Gowanda, New York (E. P. Van Duzee). ♂ ♀ September 16, 2 ♀ September 24, Forest Hills, Massachusetts, ♂ 3 ♀ October 28, 2 ♀ October 3, Crawfords, New Hampshire (H. M. Parshley). ♀ July 21, Belfast, ♂ ♀ September 7, Orono, ♀ July 17, Liberty, ♀ October 27, North East Harbor, Maine. Several specimens July and August, Parry Sound, Ontario, Canada (H. S. Parish). ♀ July 8, 1 ♂ 5 ♀ September 19, 4 ♂ 3 ♀ October 11, Truro, ♂ July 2, ♀ August 6, ♀ August 10, 3 ♂ 2 ♀ September 24, ♀ October 5, Kentville, ♀ July 15, 2 ♀ September 14, Smith's Cove, Nova Scotia; all received from William H. Brittain.

Lygus vanduzeei var. **rubroclarus** new variety

Structurally very similar to *vanduzeei* but differing greatly in general appearance; slightly smaller than the typical *vanduzeei* but larger than *pratensis*; bright ruby red, shining; pronotum and antennae marked with blackish as in *vanduzeei*.

♂. Length 6.6 mm., greatest width 2.9 mm. *Head*: width across eyes 1.22 mm., vertex .48 mm.; yellowish brown marked with red.

Antennae: segment I, length .63 mm.; II, 1.88 mm.; III, .94 mm.; IV, .85 mm.; blood-red; base and apex of segment II, and all of segments III and IV, blackish as in *vanduzeei*.

Pronotum: length 1.32 mm., width at base 2.42 mm., collar .85 mm.; bright red, marked with blackish as in *vanduzeei*, the collar and between the calli yellowish. *Scutellum* markings similar to those in *vanduzeei* except that bright red replaces the brown; cuneus bright red, more or less pale translucent inwardly.

Legs and *venter*: dark colors of *vanduzeei* all replaced by red; genital claspers apparently not differing from those of *vanduzeei*, tho a lack of material prevents dissection and comparison of a series as should be done.

♀. Usually brighter red than the male; this sex is the more abundant in the material studied.

Holotype: ♂ May 8, Smith's Cove, Nova Scotia (William H. Brittain).

Allotype: June 6, topotypic.

Paratypes: 8 ♀ June 30, Bretton Woods, New Hampshire (E. P. Van Duzee). ♀ June 29, Mount Mansfield, Vermont (G. P. Engelhardt). ♀ June 24, 2 ♀ June 26, Bretton Woods, ♀ July 3, Glen House, ♀ July 8, Mount Washington, New Hampshire; ♀ June 15, Mount Greylock, Massachusetts; ♀ July 22, ♀ July 26, Machias, 2 ♂ July 11, Capens, Maine; all collected by C. W. Johnson. ♀ June 5, Orono, Maine (H. M. Parshley). ♀ June 14, Orono, Maine. ♀ "2643" Fabyans, New Hampshire. 2 ♀ August 8, Stratton, Vermont (P. W. Whitney). ♀ Saguenay River, Province of Quebec, Canada. 3 ♂ 5 ♀ May 8 to June 6, ♀ June 23, ♀ July 15, Smith's Cove, ♂ June 24, ♂ September 24, Kentville, Nova Scotia (William H. Brittain).

Lygus convexicollis Reuter

1876 *Lygus convexicollis* Reuter
Caps. Amer. bor., p. 72.

Resembles certain forms of *pratensis* var. *oblineatus* Say but is more nearly the size of *vanduzeei*; differs from *vanduzeei* in genital claspers, in having a longer head and rostrum, and in being less shining and more pubescent.

♂. Length 6.8–7 mm. *Head*: width across eyes 1.25 mm., vertex .51 mm., length .74 mm., height at base .74 mm.; yellowish marked with black, frequently with reddish on front; gula, and sutures about tylus and lorae, black, in some cases a stripe of blackish across lorae and above base of antennae; eyes dark brownish; front with a median longitudinal reddish line, at each side showing transverse subcutaneous pale lines; lower part of face, genae, and first two segments of rostrum with long pale pubescence; carina prominent, more sharply defined than in *vanduzeei*; collum black. *Rostrum*, length 3.7 mm., reaching to middle of venter, strongly pubescent, black on apical segment and along suture.

Antennae: segment I, length .6 mm., yellowish, blackish beneath and a narrow ring at apex; II, 2.14 mm., yellowish, a narrow ring at base and the apical one-third blackish, frequently the apical half black; III, 1 mm., blackish, a narrow pale ring at base; IV, .56 mm., blackish.

Pronotum: length 1.65 mm., width at base 2.58 mm., width at anterior angles 1.2 mm., collar .88 mm.; disk strongly convex, more closely punctured and the anterior angles more sharply defined than in *vanduzeei*; pale pubescent, yellowish, faintly marked with six reddish rays on the disk, pale between; small black spot behind the inner angle of each callus, also black at basal and anterior angles, and in some cases extending down into the coxal cleft; black scutum frequently showing dark thru base of disk. *Scutellum* pale yellowish, marked as in *vanduzeei* but with black, having two median basal dashes with a black line paralleling the side margins, coarsely punctured and transversely rugose, pubescence pale; mesoscutum black, only narrowly exposed. *Sternum* opaque and black beneath, sides yellowish often marked with reddish; orifice pale tinged with reddish.

Hemelytra: greatest width 3 mm.; yellowish marked with fuscous, very similar to certain forms of *pratensis*; clavus and corium more or less irregularly blotched with fuscous; claval suture, the very thin narrow exterior edge of embolium, and extending along basal half of cuneus, black; coarsely and closely punctured, heaviest on clavus, prominent pale pubescence; cuneus with apex and a small spot at inner basal angle black. *Membrane* pale fuliginous, marked with darker; within apices of cells, a semicircular cloud just beyond the paler middle part, fuscous; veins pale.

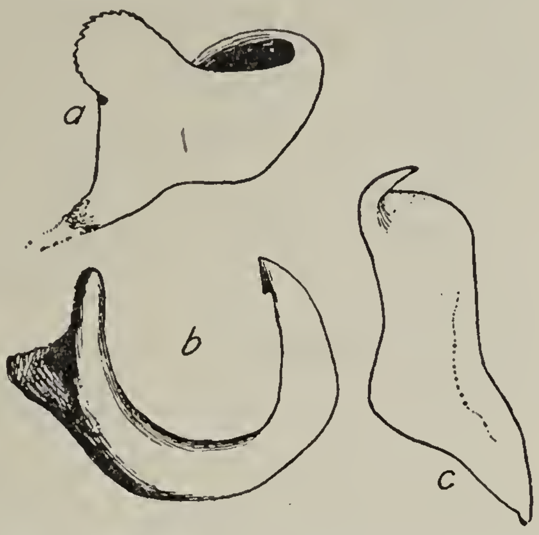

Fig. 160. LYGUS CONVEXICOLLIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Legs: yellowish marked with fuscous and black; coxae and trochanters frequently marked with fuscous; basal half of fore and middle femora shaded with fuscous on the lower side, apical half with three narrow blackish rings; basal one-third of hind femora mostly pale, a broad fuscous band in the middle and three narrower bands near the apex, the narrowest and blackest at the very apex; apices of the femora with two prominent black spines on the dorsal side; tibiae pale yellowish or tinged with greenish; spines black, a spot on the knee and a ring just below it black, apices brownish black; tarsi with basal segment, apical half of third segment, and claws, blackish.

Venter: black beneath, a wide pale stripe at sides with the latero-dorsal part brownish to fuscous; genital claspers (fig. 160) typical of the *pratensis* group, but the thick internal arm of the left clasper distinguishes the species.

♀. Very similar to the male in structure and coloration, tho usually slightly paler; second antennal segment slightly shorter (2.03 mm.), and more slender on the basal half.

Description drawn from specimens sent by E. P. Van Duzee, taken in Muir Woods, California, the type specimen being recorded from that State.

Records: 3 ♂ ♀ September 5, Muir Woods, California (E. P. Van Duzee). ♂ July 15, Sausalito, Marin County, California. 2 ♀ August, Olympia, Washington.

Lygus convexicollis var. **coloratus** new variety

Structurally not distinguishable from *convexicollis* tho slightly smaller; reddish in color, hemelytra not marked with fuscous and more or less translucent.

♂. Length 6.5 mm., greatest width 2.7 mm. *Head*: width across eyes 1.2 mm., vertex .48 mm.; yellowish marked with red; collum and apical segment of rostrum black.

Antennae: yellowish to reddish, marked with blackish as in *convexicollis*.

Pronotum: reddish, more yellowish on calli and collar; black marks on disk, xypnus, scutellum, and sternum, similar to those in *convexicollis*.

Hemelytra: entirely reddish, in some cases with yellowish and translucent in paler forms; veins and cuneus, except the center, reddish.

Legs: marked similarly to those of *convexicollis* with fuscous and dark reddish.

Venter: reddish at sides with a paler lateral stripe, blackish beneath; genital claspers showing a slight variation from those of the typical *convexicollis*, but nothing specific.

Described from specimens taken in general sweeping by Harold Morrison near Stanford University, California.

Holotype: ♂ March 26, Stanford University, California (H. Morrison).

Allotype: with the type (collection of H. Morrison).

Paratypes: 3 ♂ ♀ March 26, ♂ March 21, Stanford University, ♀ April 11, Corte Madero Creek Canyon, near Stanford University (H. Morrison).

Lygus humeralis new species

Closely related to *convexicollis*, but smaller, rostrum shorter, pronotum having very prominent humeral angles; dark reddish brown, more sepia brown above, frequently more yellowish brown in the females.

♂. Length 6.5 mm. *Head*: width across eyes 1.14 mm.; vertex .45 mm., length .63 mm., height at base .69 mm.; yellowish brown marked with reddish and black; bases of juga, and lorae, bucculae, gula, and collum, dark reddish to black; carina prominent, indented in front, vertex more or less roughened; front with indistinct transverse striae, suggestive of *striatus*; eyes reddish brown. *Rostrum*, length 2.71 mm., extending slightly beyond posterior margins of hind coxae, pale pubescent, yellowish to reddish brown.

Antennae: segment I, length .65 mm., dark reddish brown; II, 2.05 mm., reddish brown, apex fuscous; III, 1.03 mm., fuscous with reddish, narrowly pale at base; IV, .76 mm., reddish black; all segments with fine yellowish pubescence.

Pronotum: length 1.31 mm., width at base 2.18 mm., width at anterior angles 1.03 mm., collar .8 mm.; humeral angles of disk very prominent, sharply defined, more noticeable in the female; collar indented on median line above, disk coarsely and deeply punctured; dark reddish brown, usually sepia brown on the disk, shining; calli, and about the anterior angles and in some cases the collar, dark reddish with fuscous; a small black spot behind the inner margin of each callus, dark fuscous in basal angles of disk; sides coarsely punctured, dark reddish brown to fuscous, darkest about coxal cleft. *Scutellum* dark reddish brown to blackish, indistinctly marked with pale at tip and a dash each side at base; coarsely punctured and transversely rugose. *Sternum* opaque, dark reddish brown to blackish; pleura dark; orifice pale.

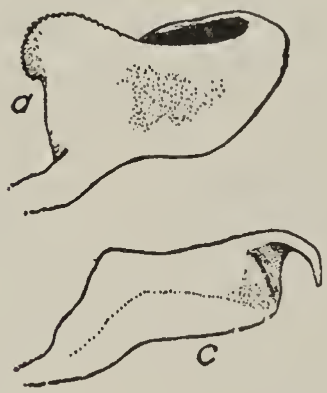

FIG. 161. LYGUS HUMERALIS, MALE GENITAL CLASPERS
a, Left clasper, lateral aspect; c, right clasper, internal lateral aspect

Hemelytra: greatest width 2.74 mm.; dark reddish brown to sepia brown with fuscous; corium bordering the embolium more or less yellowish translucent; coarsely and closely punctured, heaviest on the clavus; depressed pale yellowish pubescence; cuneus dark reddish brown to fuscous brown, usually paler in middle. *Membrane* pale, tinged with brownish bordering veins and in some cases near apex; a small but prominent fuscous mark just exterior to inner apical angles of large cells; dark specimens have a more noticeable brown cloud bordering apex of membrane.

Legs: coxae and femora dark reddish brown to blackish; tips of femora yellowish brown, the paler forms twice annulated near apices; tips of coxae and margins of trochanters paler; tibiae dark yellowish to reddish brown, two reddish black spots near base, one on the knee and the other just below, spines dark brownish; apices of tarsi darkened with fuscous.

Venter: dark reddish brown to blackish, spiracles conspicuous as pale spots; genital claspers (fig. 161) typical of the *pratensis* group, shape of the right clasper with claw very distinctive.

♀. Length 6.4 mm., width 3 mm.; slightly more robust than the male, anterior angles of pronotum more prominent, frequently more yellowish brown in color.

Holotype: ♂ July 20, Bear Lake, British Columbia.

Allotype: topotypic.

Paratypes: ♀ July 20, Bear Lake, ♂ ♀ July 2, Ainsworth, British Columbia. ♂ ♀ July 1, ♀ July 5, Revelstoke, Selkirk Mountains, British Columbia (J. C. Bradley).

Lygus columbiensis new species

Closely related to *humeralis* but differing in the genital claspers, in the shorter rostrum, and in the anterior angles of the pronotum being less prominent; mostly black beneath, reddish above marked with black.

♂. Length 6.7 mm. *Head*: width across eyes 1.16 mm., vertex .45 mm., length .57 mm., height at base .68 mm.; black, shining, lower margins of juga pale tinged with red; carina transverse, pale, closely margined with black behind; vertex mostly pale, black along the margin of each eye with a point jutting inward at top; eyes dark brown. *Rostrum*, length 2.51 mm., attaining posterior margins of hind coxae, dark reddish, segment I with apex pale, segment II blackish.

Antennae: segment I, length .63 mm., dark reddish, piceous on lower side; II, 1.91 mm., piceous; segments III and IV, broken.

Pronotum: length 1.28 mm., width at base 2.22 mm., width at anterior angles 1 mm., collar .74 mm.; disk coarsely punctured but less crowded than in *humeralis*; reddish with black, shining; calli black, with two short rays behind each callus, the black at each side extending forward on the anterior angles to the collar; basal angles of disk with black, narrow basal margin pale; sides dark reddish to blackish, margins bordering coxae pale. *Scutellum* black, shining, the apex pale with reddish; coarsely punctured, more or less transversely rugose. *Sternum* black, opaque; pleura black; margins bordering the middle coxae pale with reddish; orifice pale.

Hemelytra: greatest width 2.93 mm.; dark reddish, coarsely punctured, shining, very fine short pubescence; clavus darker bordering the scutellum, tip of the embolium piceous; cuneus uniformly dark reddish, the apex and a spot bordering embolium blackish. *Membrane* unusually clear, apical half of cells and bordering veins brownish; veins red, narrow basal angles of the membrane with fuscous; a fuscous mark at the inner apical angles of the large cells, but much less distinct than in *humeralis*.

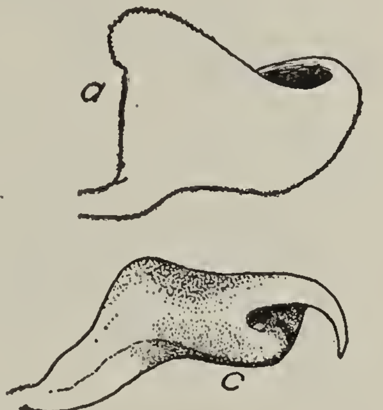

FIG. 162. LYGUS COLUMBIENSIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; c, right clasper, internal lateral aspect

Legs: coxae black, opaque; trochanters blackish with pale margins; femora dark reddish to piceous, twice annulated with piceous, contrasted with pale reddish rings;

tibiae pale reddish, marked with blackish at the knees as in *humeralis*, spines reddish to black; tarsi pale reddish, apices fuscous.

Venter: piceous, shining, a narrow reddish lateral line extending across third to seventh segments; genital claspers distinctive (fig. 162), the right clasper with a large, long claw.

Holotype: ♂ July 23, Fry Creek, British Columbia.

Lygus superiorensis new species

Closely related to *columbiensis*, but more slender, punctures on the pronotum much finer, carina arcuate toward the rear, right genital clasper distinctive; color dark reddish with black.

♂. Length 5.8 mm. *Head*: width across eyes 1.07 mm., vertex .4 mm., length .51 mm., height at base .62 mm.; carina pale, distinctly arcuate to the rear; very similar to *columbiensis* in color, except that the lorae and the tylus are dark red without black. *Rostrum*, length 2.57 mm., extending to posterior margin of the third abdominal segment; color as in *columbiensis*.

Pronotum: length 1.16 mm., width at base 2.06 mm., width at anterior angles .88 mm., collar .71 mm.; more finely punctured than in *columbiensis*, strongly shining; anterior angles more rounded, not clearly defined and margined as in *columbiensis*; calli black except for a reddish spot on the inner half, a black spot behind each inner margin, the black at outer margins extending forward to the collar; disk reddish, more dusky toward the base, darkest in the basal angles; sides reddish brown with fuscous, lower margin and bordering the coxae pale; pubescence minute, nearly glabrous. *Scutellum* dark reddish black, tip pale; coarsely punctured, transversely rugose; fine pale pubescence noticeable on the base and sides. *Sternum* black, opaque, episternum and basalar plate with reddish; margins bordering middle coxae pale; pleura and orifice very similar to those of *columbiensis* but with more reddish.

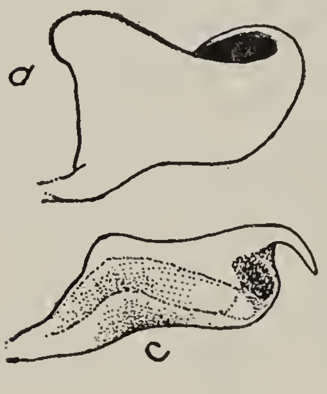

FIG. 163. LYGUS SUPERIORENSIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; c, right clasper, internal lateral aspect

Hemelytra: greatest width 2.57 mm.; dark reddish, translucent, very similar to *columbiensis* in color and structure. *Membrane* similar to *columbiensis*, faintly tinged with brownish near apex.

Legs: coxae dark reddish to piceous; femora reddish brown, fuscous on lower basal half and twice annulated with blackish near the apices; tibiae reddish brown, the apices, a spot at the knees, and the spines, reddish black; tarsi reddish brown, apices blackish.

Venter: uniformly dark reddish to piceous, spiracles apparent as pale dots; no indication of a pale lateral line as in *columbiensis*; male genital claspers (fig. 163) distinctive.

Holotype: ♂, from Sault Sainte Marie, Michigan.

Lygus atriflavus new species

Easily distinguished by the yellow color, black antennae, and black marks on the dorsum; more elongate than *pratensis*, closely related to *elisus* but differing greatly in color; claw of the right genital clasper very thick when viewed dorsally.

♂. Length 5.1–5.9 mm. *Head*: width across eyes 1.14 mm., vertex .45 mm., length .57 mm., height at base .71 mm.; yellow, smooth shining; frequently with a narrow black line extending from base of antenna up along the margin of the eye and pointing into the vertex; the darkest specimens fuscous on the tylus and front, and blackish on the dorsal margins of lorae and bases of juga; carina transverse, pale, indented before, collum black; eyes black, posterior margins yellow. *Rostrum*, length 2.28 mm., attaining posterior margins of hind coxae, yellowish, apex black.

Antennae: segment I, length .6 mm., black, in some cases brownish on dorsal side; II, 1.97 mm., black; III, 1 mm., black; IV, .6 mm., black.

Pronotum: length 1.28 mm., width at base 2.25 mm., width at anterior angles 1.03 mm., collar .77 mm.; yellow marked with black; coarsely and closely punctured, shining, pubescence minute; outer half of calli and extending forward to collar, two rays behind each callus, and irregularly across base of disk, black; in darkest specimens the rays join the black at base of disk and a third ray may be present extending back from the anterior angles; sides yellow with a black ray extending back from top of coxal cleft. *Scutellum* bright yellow, usually a short but broad black dash on median line at base; transversely rugose, punctures not distinct. *Sternum* yellow, frequently blackish along the median line beneath; pleura yellow; orifice paler.

Hemelytra: greatest width 2.62 mm., coarsely and closely punctured, heaviest on the clavus; pale pubescence, minute and oppressed; yellowish to pale and marked with black; clavus black, usually with pale each side of claval suture; corium black, usually with pale at base and along the cubitus, more yellow bordering the embolium; embolium yellow, a black spot at tip but not extending to outer margin; cuneus pale, in some cases marked with fuscous at base and tip. *Membrane* pale, lightly shaded with fuscous within the cells and clouded toward the tip; veins pale, a distinct fuscous mark at the inner apical angle of each large cell, similar to *humeralis*, *superiorensis*, and certain other forms.

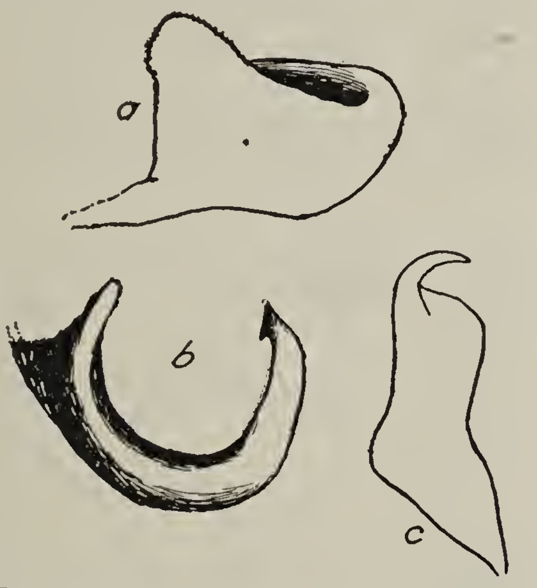

FIG. 164. LYGUS ATRIFLAVUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Legs: yellow, femora twice annulated near the apices with black, also margined with black at extreme tips; tibiae yellowish, the spines and two spots at each knee black, tips usually fuscous; tarsi fuscous, darker toward the apices.

Venter: yellow or greenish yellow, basal lobe of left clasper black; genital claspers distinctive (fig. 164), the claw on the right clasper unusually thick at base, showing best in a dorsal view.

♀. Very similar to the male in structure and coloration, only slightly more robust.

Holotype: ♂ June 7–17, Jemez Springs, New Mexico, altitude 6400 feet (John Woodgate).

Allotype: topotypic.

Paratypes: 27 ♂ ♀ June 7 to July 12, Jemez Springs, New Mexico, altitude 6400 feet (John Woodgate). ♂ 2 ♀ July 27, Kern Lake to Rock Creek, Tulare County, California, altitude 6250 to 7000 feet (J. C. Bradley). ♂ July 26, Denver, Colorado (E. C. Jackson). ♂ July 13, Rist Canyon, ♂ July 25, Rifle, Colorado; ♀, "Colo. 2213"; all received from C. P. Gillette. 3 ♀ July 23, Half Moon Lake, near Lake Tahoe, California (E. P. Van Duzee).

Lygus elisus Van Duzee

1914 *Lygus pratensis* var. *elisus* Van Duzee
San Diego Soc. Nat. Hist., Trans. **2**:20.
1916 *Lygus elisus* Van Duzee
Check list Hemip. N. Amer., p. 40.

Pale greenish with the pronotum and scutellum bright green, a small black spot behind each callus; hemelytra pallid with two fuscous marks at the tip of the corium and with dusky on the middle of the clavus; more elongate and subparallel than *pratensis*; genital claspers distinctive, showing a close affinity to *atriflavus*.

♂. Length 4.8–5.8 mm. *Head*: width across eyes 1.2 mm., vertex .45 mm., length .51 mm., height at base .71 mm.; greenish yellow, smooth shining, collum black; structurally very similar to that of *atriflavus*. *Rostrum*, length 2.11 mm., scarcely attaining posterior margins of hind coxae, yellowish, apex blackish.

Antennae: segment I, length .52 mm., pale brownish, blackish on lower side; II, 1.98 mm., dusky brown, lower side at base and extreme apex blackish; III, .85 mm., brownish, apex fuscous; IV, .6 mm., dusky brown.

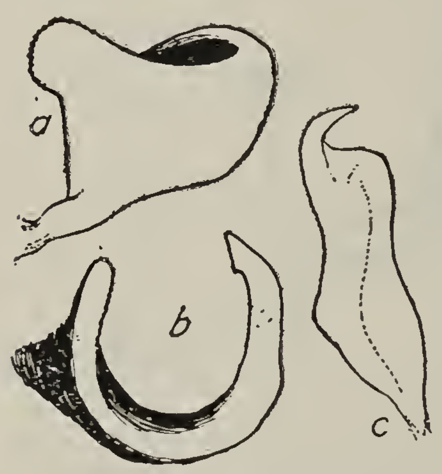

FIG. 165. LYGUS ELISUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Pronotum: length 1.4 mm., width at base 2.22 mm., width at anterior angles 1.12 mm., collar .77 mm.; coarsely, deeply, and closely punctured, minute pale pubescence; bright green, anterior margin more or less yellowish; a small black spot behind the inner margin of each callus, in some cases the inner margin of callus also black. *Scutellum* bright green, two black dashes in the middle at the base; roughly transversely rugose; mesoscutum black, scarcely exposed. *Sternum* opaque, pale to greenish yellow; pleura yellowish green; orifice pale yellowish.

Hemelytra: greatest width 2.57 mm.; pallid, translucent; clavus with a dusky cloud in the middle divided by the pale claval vein; apex of the corium with two small fuscous patches; tip of the embolium faintly tinged with fuscous; cuneus pale, extreme tip fuscous. *Membrane* clear, veins pale.

Legs: pale yellowish; femora with a wide fuscous band in the middle on the lower side, also twice annulated near the apices, extreme apical margins fuscous; tibiae with a spot on the knee and a ring just below, fuscous, spines blackish; apices of tarsi fuscous.

Venter: yellowish green; genital claspers distinctive (fig. 165), showing a close relation to *atriflavus*.

♀. Slightly more robust than the male, very similar in coloration.

Description drawn from two paratypes presented by E. P. Van Duzee, and also from several specimens collected by Dr. J. C. Bradley at Atwood, California. Originally described from San Diego County, California, where Mr. Van Duzee took the species in great numbers on Chenopodium. The specimens here recorded from South Dakota, Colorado, and Texas are typically colored like those from the type locality.

Records: ♂ 3 ♀ July 23, El Paso, Texas; 2 ♂ 2 ♀ August 2, Coconina, Arizona; ♂ 2 ♀ August 10, Imperial, California; all collected by J. C. Bradley. ♂ March 26, Stanford University, California (H. Morrison). ♂ ♀ July 9, 2 ♂ July 10, 2 ♂ July 16, 3 ♂ July 27, ♀ August 18, ♀ August 22, Ardmore, South Dakota; 7 ♂ ♀ August 22, Niobrara County, Wyoming; all collected by E. G. Holt. ♂ ♀ August 17, Grant, ♀ September 7, Denver, Colorado (E. C. Jackson). ♂ August 6, Alamosa, 2 ♀ August 12, Durango, ♂ 3 ♀ June 10, Fort Lupton, ♂ ♀ April 23, Fort Collins, Colorado (C. P. Gillette).

Lygus elisus var. **viridiscutatus** new variety

Distinguished from var. *hesperus* chiefly by the bright green scutellum and the green disk of the pronotum; base of pronotum and the hemelytra reddish.

♂. Length 5.7 mm. *Head*: yellowish green, eyes brown. *Rostrum* yellowish green, apical segment ferruginous, attaining posterior margins of hind coxae.

Antennae: similar to those of *elisus*.

Pronotum: collar and calli yellowish, disk greenish, basal half and margins reddish. *Scutellum* bright green; mesoscutum beneath pronotum blackish. *Sternum* fuscous below, yellowish to greenish on the sides.

Hemelytra: greatest width 2.4 mm.; reddish, doubtless bright red in life, costal margins paler; cuneus yellowish brown, translucent; membrane clear, lightly infumed along apices of cells, veins slightly darkened.

Legs: yellowish tinged with reddish brown, apical rings of the femora not clearly distinguished.

Venter: sides yellowish with greenish along the dorsal margins, ventral side fuscous to black.

♀. Second antennal segment slenderer than in male and yellowish brown in color; sternum and venter almost entirely yellowish or greenish; otherwise colored like the male.

This is a color variety of *elisus* possibly produced thru the effects of hibernation. All the forms thus far studied were taken early in the spring. The type specimens have been returned to E. P. Van Duzee, who sent the material for study

Holotype: ♂ April 22, San Diego County, California (E. P. Van Duzee).

Allotype: April 9, topotypic.

Paratypes: ♂ April 11, near Stanford University, California, Corte Madero Creek, lower half of the canyon, ♂ March 26, Stanford University (H. Morrison).

Lygus elisus var. **hesperus** new variety

Larger than *elisus*, the females fairly uniformly yellowish, males marked with red; this form appears to be fairly distinct from *elisus* in general appearance, but on a structural basis the forms are hard to separate.

♂. Length 6.5 mm. *Head*: width across eyes 1.22 mm., vertex .45 mm., length .57 mm., height at base .71 mm.; yellowish, smooth shining, eyes and collum black. *Rostrum*, length 2.68 mm., attaining posterior margins of hind coxae, yellowish, apex blackish.

Antennae: segment I, length .65 mm., pale reddish brown, fuscous on lower side; II, 2.11 mm., reddish, apex and lower side at base blackish; III, 1 mm., dark reddish brown to fuscous; IV, .63 mm., fuscous.

Pronotum: length 1.34 mm., width at base 2.28 mm., width at anterior angles 1.08 mm., collar .83 mm.; structurally very similar to that of *elisus*; yellowish, bright yellow between calli and just before; outer half of calli and a small round spot behind each inner margin, a spot within basal and anterior angles of disk, and a small spot behind coxal cleft, black. *Scutellum* bright yellow, two median basal dashes black; mesoscutum scarcely exposed, black. *Sternum* opaque, black beneath, sides yellowish; pleura yellowish, orifice paler.

Hemelytra: greatest width 2.68 mm.; more pallid than yellowish; apex of clavus and suture, apical half of corium, and tip of embolium, reddish or marked with red; inner margin and tip of cuneus reddish. *Membrane* pale, faintly shaded with brownish bordering the veins, a darker mark at the inner apical angles of the large cells.

Legs: yellowish, more or less shaded with reddish; markings on the femora similar to those in *elisus* but more reddish in color; tibiae yellowish, apices reddish, spines black; tips of tarsi fuscous.

Venter: fuscous beneath, sides yellow; genital claspers similar to those of *elisus*, no differences being shown in a figure.

♀. More uniformly yellowish than the male, pronotum entirely yellow except for a small black dot behind the inner margin of each callus; hemelytra uniformly pallid without reddish; markings on the femora more reduced; venter yellow; second antennal segment slightly more slender, in color rather brownish than red.

The type specimens are from material presented by C. H. Kennedy, who found this form fairly abundant about the alfalfa fields on Santa Cruz Island, California.

Holotype: ♂ July 26, Santa Cruz Island, California (C. H. Kennedy).

Allotype: topotypic.

Paratypes: 48 ♂ ♀ July 26, Santa Cruz Island, California (C. H. Kennedy). ♂ August 15, Ramona, ♂ August 7, Descanso, 2 ♂ August 6, Atwood, San Diego County, 3 ♂ ♀ Brawley, California (J. C. Bradley). 4 ♀, Pasadena, Los Angeles County, California (F. Grinnell, jr.). 3 ♂ June 11, Jacumba-Campo, San Diego County, ♂ ♀ June 2, Santa Barbara, California (H. Morrison).

Lygus plagiatus Uhler

1895 *Lygus plagiatus* Uhler
Hemip. Colo., p. 35.

More robust than *pratensis*, black with greenish yellow, mottled; head and anterior part of the pronotum yellowish or olive green, hemelytra irregularly mottled with black and paler spots; differs from *pratensis* in the antennal segments and in the form of the right genital clasper.

♂. Length 5.3 mm. *Head*: width across eyes 1.2 mm., vertex .51 mm., length .57 mm., height at base .74 mm.; yellowish green marked with black, shining; median line of front and two slender irregular lines each side, eyes, and usually apical half of tylus, blackish; structurally very similar to that of *pratensis*. *Rostrum*, length 2.08 mm., reaching only slightly beyond posterior margins of middle coxae, greenish yellow, apex blackish.

Antennae: segment I, length .54 mm.; brownish black; II, 1.71 mm., yellowish brown, base and apical one-fourth blackish; III, 1 mm., fuscous, greenish yellow at base; IV, .94 mm., fuscous.

Pronotum: length 1.25 mm., width at base 2.22 mm., width at anterior angles 1.14 mm.; coarsely and sparsely punctate, shining, minute pale pubescence; greenish yellow marked with black, mostly black in dark specimens; outer half of calli and extending forward to collar, two rays behind each callus and usually extending to join black on basal margin, black; disk narrowly margined with pale; lower side margins pale yellowish with a wedge-shaped black ray extending back from top of coxal cleft. *Scutellum* blackish, two yellowish spots at base, one each side of middle, the apical half with a pale median vitta, in pale specimens the lateral margins yellowish; transversely rugose, pale pubescent; mesoscutum prominently pale pubescent. *Sternum* black, opaque, marked with yellowish at sides; pleura blackish; margins of sclerites and basalar plate greenish yellow; orifice pale.

Hemelytra: greatest width 2.8 mm.; broader than *pratensis*, blackish and irregularly mottled with greenish yellow; narrow lateral margin of embolium and apex black; cuneus greenish yellow, the apex and a spot at the base opposite the embolium black. *Membrane* fuscous, veins pale; usually the middle, and an area each side of the middle, paler.

Legs: yellowish or greenish yellow, apical half of femora marked with black; front and middle femora with two fuscous rings near the apices, the posterior pair twice annulated with black and yellowish toward the apices, in addition a third and wider blackish band at the middle; tibiae yellowish, the spines, a spot on the knee, and a ring just below, black, tips fuscous; tarsi yellowish, blackish at tips.

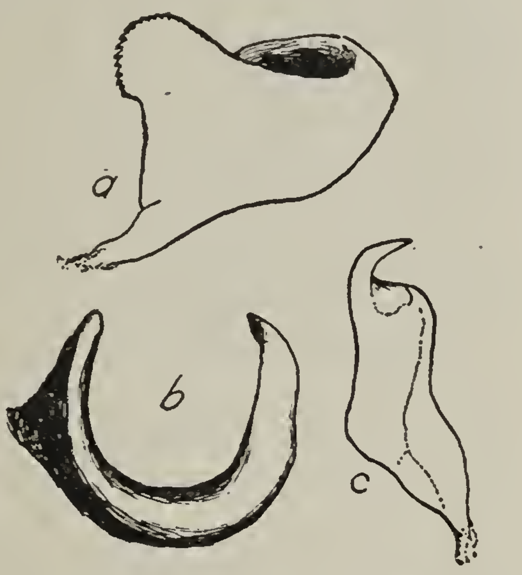

FIG. 166. LYGUS PLAGIATUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Venter: black, yellowish on the lower side at base, spiracles surrounded with yellowish or greenish; genital claspers (fig. 166) typical of the *pratensis* group; shape of the claw on the right clasper easily separates the species from *pratensis*.

♀. Slightly more robust than the male and usually paler in color; second antennal segment shorter (1.57 mm.); pronotum more yellowish, black rays behind the calli frequently not reaching the black basal margin; venter greenish yellow, blackish on the vagina exterior, dark specimens with the black more extended.

The species is found by sweeping in weed fields, it usually occurring on ragweeds tho apparently never in abundance. Mr. Van Duzee took the species on great ragweed (*Ambrosia trifida*) near Buffalo, New York.

Records: 2 ♂ July 15, Springfield, ♂ July 22, Hollister, Missouri; ♀ July 24, Ithaca, New York; all collected by H. H. Knight. 3 ♂ 2 ♀ September 18, Buffalo, New York (E. P. Van Duzee). ♀ March 3, 2 ♀ October 1, Maspeth, 4 ♂ 3 ♀ Forest Hill, Long Island; ♀ May 2, White Plains, New York; ♂ 3 ♀ July 30, Pigeon Cove, Massachusetts; all collected by C. E. Olsen. ♂ September 30, Forest Hills, Massachusetts (H. M. Parshley). ♂ April 25, Kingston, Rhode Island. ♀ August 29, Madison, New Jersey (Wm. T. Davis). ♀ November

25, Columbia, Missouri (C. R. Crosby). ♂ 2 ♀ June 10–21, Atherton, Missouri (C. F. Adams). 2 ♀ August 11, Charleston, Missouri (E. H. Gibson).

Lygus striatus new species

Easily distinguished by the transverse striae on the front of the head, the pallid color, and the black markings about the calli; in general appearance resembling *nigropallidus* but easily separated by the form of the claw on the right genital clasper.

♂. Length 5.5 mm. *Head*: width across eyes 1.22 mm., vertex .48 mm., length .54 mm., height at base .7 mm.; front of head with seven or eight striae each side of median line, nearly transverse but inclined slightly downward; pale yellowish, narrowly black surrounding the antennal socket and in a line extending immediately above, eyes dark brownish, collum black. *Rostrum*, length 1.72 mm., not reaching posterior margins of middle coxae, yellowish, apex blackish.

Antennae: segment I, length .54 mm., yellowish, a blackish line on lower side; II, 1.54 mm., pale yellowish brown, fuscous at apex; III, .74 mm., fuscous, narrowly pale at base; IV, .6 mm., blackish.

Pronotum: length 1.12 mm., width at base .77 mm., width at anterior angles 1.12 mm., collar .74 mm.; coarsely, rather deeply, and closely punctate, fine pale pubescence; pale, more or less yellowish, a black spot within basal angles; calli with inner and front margins, outer half and extending forward to collar, and a spot behind each inner angle, black; sides with a black ray extending back from top margin of coxal cleft. *Scutellum* pale yellowish, black on base, two median black dashes extending from base and joined beyond middle at each side by a black line running parallel with lateral margins; transversely rugose, pale pubescent. *Sternum* blackish beneath, opaque, yellowish at sides; pleura pale yellowish, in some cases shaded with fuscous; orifice pale.

Hemelytra: greatest width 2.68 mm.; pallid, middle of clavus and apical half of corium irregularly spotted with fuscous; extreme claval margins bordering the scutellum blackish; punctures on the clavus broad, shallow, and closely placed; pubescence pale and closely appressed; cuneus pale yellowish, scarcely darkened at tip. *Membrane* pale brownish, blackish in the basal angles; a longitudinal fuscous cloud extending from within the apex of each large cell to near the tip, where both fuse in an arc.

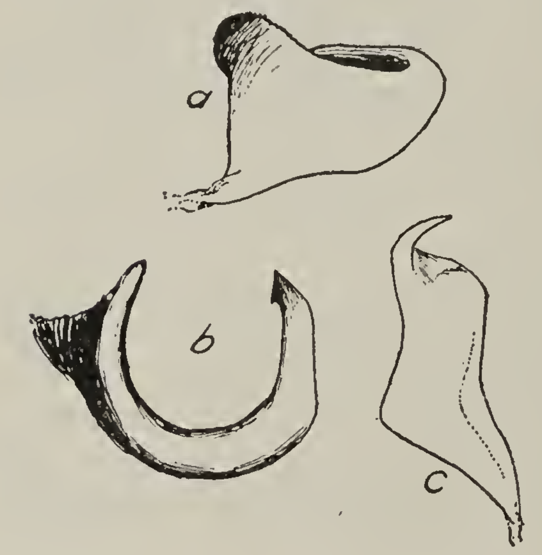

FIG. 167. LYGUS STRIATUS, MALE GENITAL CLASPERS
a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Legs: pale yellowish, femora twice annulated near apices with fuscous, extreme apical margins blackish; tibiae with a fuscous spot on the knee and usually a second one just below, spines dark brownish to black; tarsi yellowish, apices fuscous.

Venter: dull yellowish, dark brownish to fuscous on the lower side, darker nearer the base; genital claspers (fig. 167) characteristic of the *pratensis* group; the form of the right clasper, taken in connection with the short rostrum and the striae on the front of the head, separates the species from all others.

♀. Very similar to the male in size and coloration, second antennal segment shorter (1.4 mm.) as is usual in the *pratensis* group.

Holotype: ♂ July 27 to August 1, Kern Lake to Rock Creek, Tulare County, California, altitude 6250–7000 feet (J. C. Bradley).

Allotype: topotypic.

Paratypes: 4 ♀, topotypic.

Lygus nigropallidus new species

Closely related to *striatus* but more shining above and black beneath; differs in the black markings on the head and about the calli; right genital clasper with the claw longer and more extended than in *striatus*.

♂. Length 5.3 mm. *Head*: width across eyes 1.16 mm., vertex .48 mm., length .54 mm., height at base .68 mm.; pale or dull yellowish marked with black; front having striae but not so distinct as in *striatus*; two irregular black lines extending up from the base of each antenna, the inner pair joining across the front while the outer lines curve up by the eye and point to a spot on the vertex; bases of juga, gula, margins of lorae, eyes, and collum, black; in some cases tylus reddish or fuscous at sides; carina slightly arcuate to rear, a depression from corner of each eye extending to center of vertex. *Rostrum*, length 1.77 mm., scarcely reaching posterior margins of middle coxae, pale, blackish.

Antennae: segment I, length .51 mm., pale yellowish, blackish on lower side; II, 1.42 mm., yellowish brown, base and apex fuscous; III, .77 mm., fuscous, brownish at base; IV, .68 mm., fuscous.

Pronotum: length 1.2 mm., width at base 2.08 mm., width at anterior angles 1.02 mm., collar .77 mm.; punctures more distinct and disk more shining than in *striatus*; calli pale or brownish, shining, two black spots or short rays behind each, black on the inner margins; a black ray extending back from top of coxal cleft, also blackish in the stricture and extending back as a short ray inside anterior angles of disk. *Scutellum* black, a median pale vitta with a small spot each side at base, in some cases yellowish along the lateral margins; rather roughly transversely rugose, pale pubescence. *Sternum* black, opaque, in some cases slightly brownish at the sides; pleura blackish, pale to brownish at the margins; orifice pale.

Hemelytra: greatest width 2.45 mm.; pallid, translucent, black dorsum of the venter showing thru; clavus fuscous along the middle each side of the pale claval vein; corium irregularly blotched with pale fuscous, somewhat similar to that of *striatus*; extreme outer edge of embolium and cuneus fuscous; cuneus pale yellowish, translucent, slightly darkened with fuscous along the basal margins; punctuation and pubescence very similar to that in *striatus*. *Membrane* pale, darkened with fuscous brown bordering both sides of the veins; apical half clouded with fuliginous.

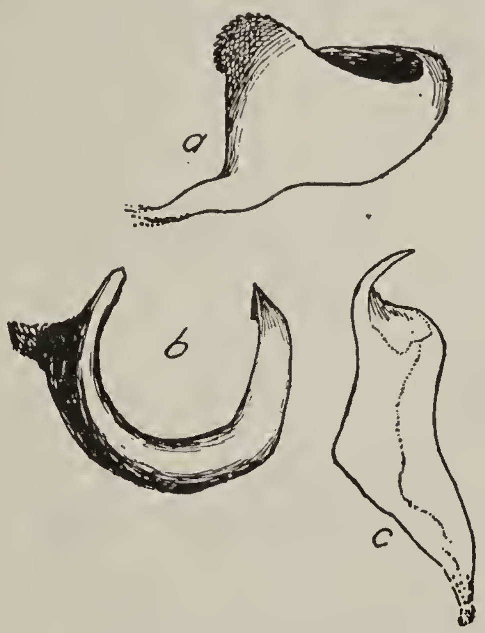

FIG. 168. LYGUS NIGROPALLIDUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Legs: coxae blackish, paler at apices; femora brownish to fuscous, twice annulated with pale near the apices; tibiae pale, the spines, a spot on the knee, and one just below, blackish: tarsi yellowish brown, apices fuscous.

Venter: black, shining, having a golden luster, spiracles appearing as pale spots; genital claspers (fig. 168) typical of the *pratensis* group, distinguished from those of *striatus* by the longer and more extended slender claw on the right clasper.

♀. Length 6.1 mm., greatest width 2.85 mm.; slightly larger and more robust than the male, very similar in coloration, the last abdominal segment somewhat pale.

Holotype: ♂ June 7–17, Jemez Springs, New Mexico, altitude 6400 feet (John Woodgate).

Allotype: topotypic.

Lygus aeratus new species

Fuscous brown tinged with bronze; transverse striae on the front of the head; hemelytra with small patches of silvery pubescence, somewhat suggestive of *plagiatus* in this respect.

♂. Length 5.7 mm. *Head*: width across eyes 1.11 mm., vertex .45 mm., length .51 mm., height at base .68 mm.; brownish with fuscous, shining; front with five nearly transverse striae, broken at middle by the median line; vertex nearly flat, slightly grooved in the middle; basal carina prominent, yellowish. *Rostrum*, length 2.45 mm., dark fuscous brown, paler at joints, scarcely reaching posterior margins of hind coxae.

Antennae: segment I, length .57 mm.; II, 1.71 mm.; III, .77 mm.; IV, .57 mm.; brownish bronze, last two segments darker.

Pronotum: length 1.48 mm., width at base 2.45 mm., width at anterior angles 1.14 mm., collar .83 mm.; brownish to bronze, shining; collar and calli more ferruginous, sides nearly black; disk with five rather indistinct pale rays; punctures coarse, deep, and rather closely placed. *Scutellum* dark brownish to black, tip paler; punctures confluent and roughly transversely rugose. *Sternum* dark fuscous brown, opaque; orifice pale, posterior lobe nearly white.

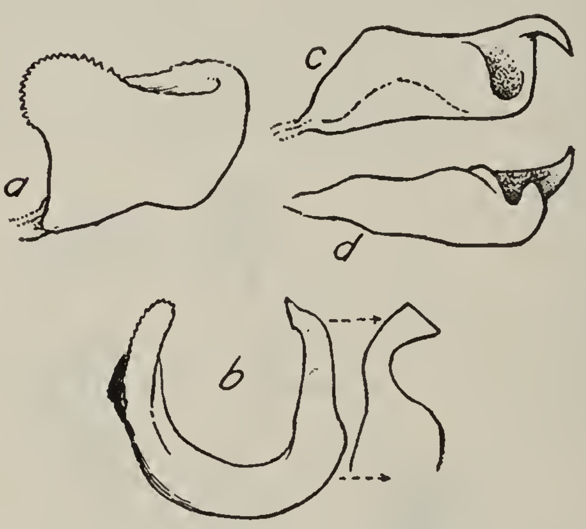

FIG. 169. LYGUS AERATUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect; d, right clasper, ventral aspect

Hemelytra: greatest width 2.7 mm., lateral margins curved; fuscous brown tinged with bronze; small patches of silvery pubescence set in a field of fine golden pubescence; translucent spots in evidence along the exterior margin of the corium and at base of the claval suture; clavus and corium rather coarsely and closely punctured; cuneus brownish to fuscous, only slightly translucent. *Membrane* clear, veins and narrow margin next to them lightly infumed, a dark brownish mark bordering the inner apical angles of the larger cells.

Legs: dark brownish to ferruginous; anterior coxae with a prominent puncture on the front side near the base; femora with a pale ring at apex with indications of a second annulus just before; tibiae yellowish brown, spines ferruginous, a spot on the knee and a ring just below fuscous to ferruginous; tarsi yellowish brown with apices and claws blackish.

Venter: brownish black to ferruginous, pale surrounding spiracles; genital claspers (fig. 169) typical of the group, right clasper distinctive of the species.

♀. Slightly broader than the male, with costal margin more curved; somewhat variable in shade of color, ranging from the typical brownish bronze to dark fuscous bronze.

Holotype: ♂ July 15, Mount Tallac, near Lake Tahoe, California (E. P. Van Duzee).

Allotype: topotypic.

Paratypes: 2 ♀ July 22, 2 ♀ July 23, Mount Tallac, near Lake Tahoe, California (E. P. Van Duzee). 2 ♀ July 19, Alta Meadows, Sequoia National Park, California, altitude 9000 feet (J. C. Bradley); these two specimens much darker in color than those taken on Mount Tallac.

The type specimens have been returned to Mr. Van Duzee.

Lygus bradleyi new species

In general appearance suggestive of *distinguendus* but differing in the shape of the pronotum and the scutellum; dark yellowish gray marked with black; genital claspers distinctive of the species.

♂. Length 5–6.3 mm. *Head*: width across eyes 1.2 mm., vertex .47 mm., length .54 mm., height at base .68 mm.; front with striae rather similar to those in *striatus*; black with pale brownish; a spot at base and the lower margins of juga, the middle part of lorae, a spot beneath the eye, each side of median line in front, carina, and across vertex just in front, black; eyes brown or dark brown; pale sericeous pubescence. *Rostrum*, length 1.88 mm., scarcely attaining posterior margins of middle coxae; pale brownish, shaded with blackish at joints and apex.

Antennae: segment I, length .54 mm., yellowish brown, blackish beneath and shaded with fuscous on upper side at base; II, 1.57 mm., yellowish brown, base and apical one-third blackish; III, .75 mm., dark brownish to fuscous, narrowly pale at base; IV, .68 mm., fuscous.

Pronotum: length 1.25 mm., width at base 2.11 mm., width at anterior angles 1.03 mm., collar .74 mm.; punctures deep and closely placed, fine pale pubescence; calli distinctly elevated, defined behind by an impressed line; yellowish brown or olive-gray marked with black; margins of calli, two rays behind each callus and one at either side extending from the anterior angles, collar, and just before the calli, black; in a dark specimen the disk is mostly blackish, with a median line and two rays at each side paler; sides and xyphus black with pale on the margins and bordering the coxal cleft. *Scutellum* black, a median vitta and a dash each side at base pale, the narrow lateral margins usually pale yellowish; rather coarsely transversely rugose, prominent pale sericeous pubescence. *Sternum* black, opaque, pale at base of middle coxae; pleura black with margins yellowish; orifice pale.

Hemelytra: greatest width 2.57 mm.; blackish mottled with yellowish and gray, the pattern suggestive of *distinguendus*; punctures broad and shallow, closely placed, pale sericeous pubescence; corium mostly dark, mottled with yellowish spots; cuneus pale translucent, outer margin and tip brownish black, basal half mostly dark but irregularly flecked with pale. *Membrane* pale fuscous, a spot each side of middle, basal half of cells, and bordering cuneus, paler.

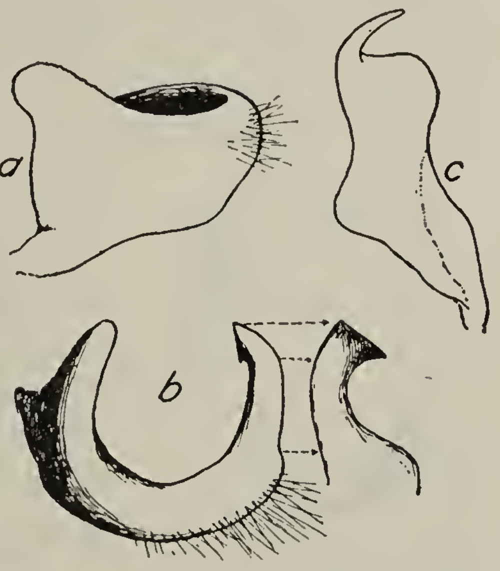

FIG. 110. LYGUS BRADLEYI, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Legs: coxae black, tips and margins of trochanters pale, femora blackish, twice annulated near apices with pale; tibiae pale yellowish, the spines, a spot at the knee, and one just below, black, apices fuscous; tarsi dark yellowish, apices and claws blackish.

Venter: black, shining, a stripe along the sides and narrowly surrounding the spiracles pale; genital claspers (fig. 170) distinctive of the species, pubescence unusually prominent.

♀. The female has not been studied but is doubtless very similar to the male in coloration.

Holotype: ♂ June 20–27, Blue Lake, Humboldt County, California (J. C. Bradley).

Paratype: ♂ May 29, Pacific Grove, California (H. Morrison).

Lygus nubilus Van Duzee

1914 *Lygus distinguendus* var. *nubilus* Van Duzee
San Diego Soc. Nat. Hist., Trans. **2**:20.

Yellowish brown, mottled and clouded with fuscous or black; resembling *ultranubilus* and *nubilatus* most closely; genital claspers distinctive of the species.

♂. Length 4.3 mm. *Head*: width across eyes 1 mm., vertex .4 mm., length .4 mm., height at base .57 mm.; yellowish brown tinged with fuscous; genae fuscous, vertex and front usually shaded with fuscous each side of the pale median line; eyes dark brown, pale at margins, extending back at sides as far as the constriction behind the collar. *Rostrum*, length 1.91 mm., attaining posterior margins of hind coxae, yellowish brown, apex blackish.

Antennae: segment I, length .4 mm., yellowish; II, 1.25 mm., yellowish, rarely darker at apex; III, .62 mm., yellowish tinged with fuscous; IV, .51 mm., fuscous; segment II slightly longer and thicker on the apical half than in the female.

Pronotum: length .91 mm., width at base 1.57 mm., width at anterior angles .83 mm., collar .63 mm.; punctures closely placed, rather deep and prominent, fine pale pubescence; dull yellowish brown, a spot behind inner angles of calli and a larger one in each basal angle of the disk blackish; calli in some cases with fuscous at outer margins; a pale ridge extending back on sides from top of coxal cleft, fuscous just above this and brownish below. *Scutellum* moderately arched, transversely rugose in the middle on the basal half; dark brownish to fuscous, median line and basal angles pale, extreme tip white; prominent pale pubescence at sides and on mesoscutum. *Sternum* fuscous, opaque beneath; margins bordering middle coxae pale; pleura fuscous; margins of the sclerites pale; orifice white.

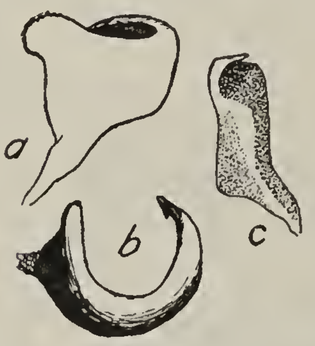

FIG. 171. LYGUS NUBILUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Hemelytra: greatest width 1.88 mm.; yellowish brown more or less mottled with fuscous; corium and embolium fuscous at apex, more or less spotted toward the middle; cuneus yellowish translucent, darkened with fuscous or reddish at apex and along the basal margin; finely and closely punctured, heaviest on the clavus; pale pubescence apparent only in small patches. *Membrane* fuscous, a spot each side of the middle near the margin, a smaller one in the middle, and the vein at the apex of the larger cell, pale.

Legs: pale to yellowish brown; coxae fuscous; femora yellowish, twice annulated with fuscous near the apices, posterior pair with a third and wider band around the middle; tibiae with a fuscous spot on the knee and a second one just below, spines yellowish; tips of tarsi fuscous.

Venter: dark brownish to fuscous, a more or less broken pale stripe on the sides; genital claspers (fig. 171) distinctive of the species.

♀. Very similar to the male in size and coloration; second antennal segment slightly shorter and more slender.

Description drawn from a pair of paratypes presented by Mr. Van Duzee. The type material comes from San Diego County, California, the author stating (Van Duzee, 1914:21): "Described from numerous examples taken on elderberry trees growing along the streams and gullies throughout the county. This tree or shrub has a powerful and exceedingly disagreeable and suffocating odor which is not alluded to in any botanical work on this region to which I have access."

Lygus ultranubilus new species

Closely related to *nubilus*, but more ovate and robust and much darker in color; lower half of the head thicker and the rostrum slightly shorter; genital claspers distinctive of the species.

♂. Length 3.8 mm. *Head*: width across eyes 1.05 mm., vertex .44 mm., length .43 mm., height at base .63 mm.; lower half of head thicker than in *nubilus*; yellowish brown, bases of juga, upper and lower margins of lorae, arched part of tylus, genae, and bases of bucculae, blackish; each side of the median line on the front, and a spot each side of the vertex, fuscous. *Rostrum*, length 1.52 mm., scarcely attaining posterior margins of hind coxae, yellowish brown, basal segment and apex blackish.

Antennae: segment I, length .38 mm., yellowish, fuscous on the lower side; II, 1.22 mm., yellowish, fuscous at base and apex; III, .64 mm., fuscous; IV, .48 mm., slightly darker than segment III.

Pronotum: length .96 mm., width at base 1.71 mm., width at anterior angles .85 mm., collar .71 mm.; broader in proportion to length, more coarsely and deeply punctured on center of disk than in *nubilus*; very similar to that of *nubilus* in black markings, but usually with two black spots behind the calli and the black in the basal angles of the disk extending across to the middle. *Scutellum* marked as in *nubilus* but with more blackish, basal half more strongly arched. *Sternum* black, opaque beneath; margins bordering the middle coxae white; pleura blackish; orifice white.

Hemelytra: greatest width 1.97 mm.; blackish, mottled with yellowish brown across the middle of the corium; a large patch at apex of clavus and basal half of embolium yellowish brown; extreme outer edge of embolium blackish; cuneus pale, basal half and apex blackish; more finely and closely punctured than in *nubilus*. *Membrane* fuscous, marked with pale much as in *nubilus*.

Legs: coxae blackish, trochanters pale; femora and tibiae marked similarly to those in *nubilus* except that the front and middle femora are fuscous on the basal half in addition to the two rings near the apices; tibial spines and apices of tarsi fuscous to blackish.

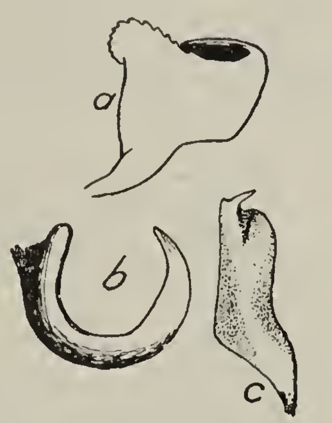

FIG. 172. LYGUS ULTRANUBILUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Venter: blackish with an indication of a pale stripe on the sides; female more brownish with fuscous; genital claspers distinctive (fig. 172), the shape of the claw on the right clasper easily separating this species from *nubilus*.

♀. Length 4.3 mm., width 2.17 mm.; more robust than the male, usually not so dark-colored; second antennal segment slightly shorter and more slender.

Holotype: ♂ July 12, Jemez Springs, New Mexico, altitude 6400 feet (John Woodgate).

Allotype: topotypic.

Paratypes: 2 ♂ 4 ♀, topotypic. ♀ August 13, Fort Collins, Colorado. 2 ♀ August, Glen Sioux County, Nebraska (H. G. Barber).

Lygus nubilatus new species

Resembles *nubilus* and might be taken for a pale form of that species, but differs in that the male has the second antennal segment thicker in proportion, the head and the apex of the pronotum more narrowed, the scutellum more evenly arched, and the median basal part not so heavily punctured and depressed; genital claspers show certain differences, as seen in figures 171 and 173.

♂. Length 4.4 mm. *Head*: width across eyes .91 mm., vertex .31 mm., length .37 mm., height at base .57 mm.; face pale to yellowish, sutures about tylus, juga, and lorae, with red; a subcutaneous fuscous line extending from basal corner of eye into the vertex, curving back and running parallel with the margin of the eye to a point just above the base of the antenna; front in some cases with red either side of the median line, tylus pale on the apical half and usually with lines on the basal part; fuscous on the gula and the upper surface of the rostral segment. *Rostrum*, length 1.77 mm., just attaining posterior margins of hind coxae, pale with yellowish, black at tip and fuscous on the upper side of the first segment.

Antennae: segment I, length .48 mm., pale to yellowish, fuscous on lower side; II, 1.22 mm., yellowish brown with a fuscous band at base and apex, noticeably thickened beyond the fuscous basal part, thicker than in the male of *nubilus*, in the female not so thick; III, .71 mm., fuscous to black, paler at base; IV, .48 mm., black; vestiture of fine yellowish pubescence.

Pronotum: length .94 mm., width at base 1.65 mm., width at anterior angles .74 mm., collar .63 mm.; pale with white and clear areas; fuscous or reddish brown spot just inside the margin of the basal angles; collar, anterior part of calli, basal margin and median line of disk, pale to white; yellowish to brownish just behind calli and near basal margin of disk; punctures not so closely placed as in *nubilus*. *Scutellum* pale, with two median basal dashes and one each side near the lateral margins brownish to fuscous, purplish red in females; noticeably arched, only slightly depressed and rugose at basal dashes. *Sternum* fuscous below, with pale on the sides.

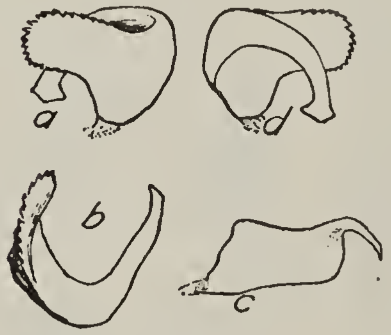

FIG. 173. LYGUS NUBILATUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect; d, left clasper, internal lateral aspect

Hemelytra: greatest width 2 mm.; pale with brown patches; clavus with brown spots or united into patches, usually a median longitudinal pale line broadening at apex; apices of corium and embolium with a broad transverse brownish to fuscous patch, basal half flecked or with patches of brownish or fuscous; vestiture of pale yellowish pubescence; cuneus clear, with apex and a small dot at exterior basal angles fuscous or purplish red. *Membrane* and veins fuscous, paler in the center and along the veins at apices of cells; female specimens with the veins reddish.

Legs: pale, femora with two fuscous or reddish rings near the apices, in some cases a reddish patch on the lower side near the middle; fuscous spot on the knee, with a second slightly lower on the tibia, tips of tibiae brownish, spines pale brownish; apices of tarsi fuscous to black.

Venter: pale, brownish to fuscous along the lateral margins, genital segment light brownish; genital claspers (fig. 173) distinctive of the species.

♀. Length 4.2 mm., greatest width 1.88 mm.; differs from the male chiefly in the second antennal segment being more slender, and the brownish colors running more to reddish than to fuscous as in the male; last two segments of venter tinged with reddish or fuscous.

Holotype: ♂ September 5, Muir Woods, California (E. P. Van Duzee).

Allotype: May 16, Piedmont, California (E. P. Van Duzee).

Paratypes: 8 ♀ May 16, 1915, Piedmont (E. P. Van Duzee).

The type specimens have been returned to Mr. Van Duzee, who lent the material for study.

Lygus nubilosus new species

Allied to *nubilatus* but is larger and more brownish in color, differs in the relative width of the head and the vertex, and the second antennal segment in the male is more slender; genital claspers characteristic of the species.

♂. Length 4.8 mm. *Head*: width across eyes .94 mm., vertex .37 mm., length .4 mm., height at base .57 mm.; yellowish marked with fuscous and reddish; two brownish triangles on the vertex, pointing inward and separated by the yellowish median line, front with a yellowish median line separated from that of vertex by a brownish arc; juga, apex of tylus, and arched part of lorae, pale; sutures with reddish, and tips of lorae blackish; basal carina scarcely raised from vertex. *Rostrum*, length 1.82 mm., reaching posterior margins of hind coxae, yellowish brown, apical segment blackish.

Antennae: segment I, length .51 mm., yellowish brown, blackish beneath; II, 1.34 mm., dark brownish, darker at base and apex; III, .71 mm., brownish black; IV, .48 mm., blackish; vestiture of fine yellowish pubescence.

Pronotum: length 1 mm., width at base 1.79 mm., width at anterior angles .74 mm., collar .6 mm.; brownish, shining, spot just inside the margin of the basal angles darker; collar, inner half of calli, triangle just before and a spot behind inner angles of calli, margins bordering coxal cleft, narrow basal margin, and an indication of a median line at base, pale yellowish; punctures deeper and more crowded than in *nubilatus*. *Scutellum* dark brownish, the pale median line not reaching base but widening from middle to involve most of apex, a pale line at each side parallel with side margins and attaining basal angle, extreme lateral margins also usually pale; the brown color taking the form of two median basal dashes which attain the middle, a spot along each side margin being cut off by the pale color. *Sternum* fuscous to blackish beneath, sides yellowish with some brownish; metasternal orifice pale.

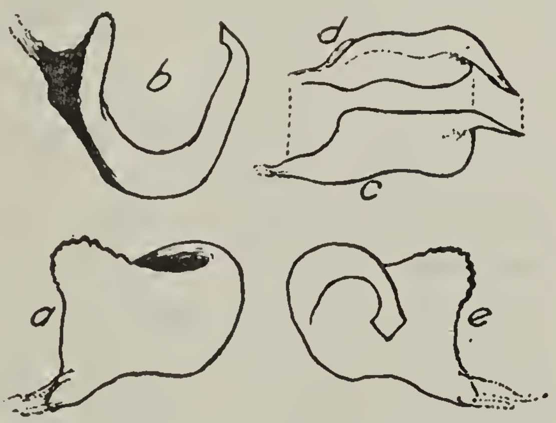

FIG. 174. LYGUS NUBILOSUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect; d, right clasper, dorsal aspect; e, left clasper, internal lateral aspect

Hemelytra: greatest width 2 mm.; brownish, base of corium and embolium, middle part of embolium and that part of the corium bordering it, tip of embolium bordering the fracture, yellowish brown and translucent; raised margin at inner apical angles of corium pale; cuneus pale yellowish, translucent, the outer basal angles and the apex dark brownish to fuscous, the inner angles and the margin narrowly reddish; punctures indistinct, more or less scabrous, fine pale pubescence. *Membrane* pale fuscous, a median spot and one each side near the margin, and a narrow margin bordering the cuneus, clear, veins reddish.

Legs: pale with yellowish; coxae blackish at extreme base; femora with two reddish brown rings near the apices and a large spot near the middle on the lower side of the posterior pair; tibiae yellowish brown, spines darker, knees with blackish and a smaller spot just below; apices of tarsi dark brownish.

Venter: pale with reddish brown and fuscous; base of genital segment dark brownish with fuscous, paler about tip; an indistinct broad lateral stripe, brownish with some reddish; narrow dorso-lateral margin and the spiracles pale; genital claspers (fig. 174) showing a close relationship to *nubilatus* but differing in many respects as seen in the figure.

Holotype: ♂ May 21, 1902, Cloudcroft, New Mexico; collection of E. P. Van Duzee.

Allotype: July 13, Palmer Lake, Colorado.

Paratypes: 2 ♂ July 13, Palmer Lake, ♂ July 14, Pikes Peak, Colorado (C. P. Gillette). ♀ August 9, Emigration Canyon, Utah (A. Wetmore).

Lygus distinguendus Reuter

1875 *Lygus distinguendus* Reuter
Pet. nouv. ent., p. 544.
1896 *Lygus distinguendus* Reuter
Hemip. gymn. Eur. V, p. 74.
1909 *Lygus distinguendus* Reuter
Bemerk. neark. Caps., p. 45.

The following description for this species is drawn from the single female specimen mentioned by Reuter (1909), from Glacier, British Columbia, which the writer was able to study thru the kindness of Mr. O. Heidemann at the National Museum.

♀. Length 5.1 mm. *Head*: width across eyes .97 mm., vertex .43 mm., length .48 mm.; face and vertex black except a small spot on either side at base of tylus and a white triangular spot at top margin of eye and pointing into the vertex. *Rostrum* just attaining posterior margins of middle coxae.

Antennae: segment I, length .37 mm.; II, 1.14 mm.; III, .6 mm.; IV, .45 mm.; dark ferruginous brown to blackish in color.

Pronotum: length .88 mm., width at base 1.77 mm., width at anterior angles .88 mm.; dark brownish to black, lighter on the basal half; calli dark fuscous brown surrounded by blackish which extends along the collar thence along the lateral margin of the disk; side margins and bordering the anterior coxae and coxal cleft, pale; punctures fine and closely placed, transversely confluent over basal half of disk. *Scutellum* broad and flat, transversely rugose, dark brownish with tip pale as in *rubicundus*. *Sternum* dark ferruginous to black, narrow margin bordering the middle coxae white; orifice pale.

Hemelytra: dark reddish brown; ash-gray sericeous pubescence forming spots with darker pubescence between; pale point at tip of costa bordering the fracture, also a point of white at extreme tip of corium next to inner angle of cuneus; cuneus dark reddish brown, somewhat translucent in the middle and nearly black at tip. *Membrane* brownish to fuscous, bordering the veins and a spot either side of the middle paler, an area bordering tip of cuneus clear, cell veins pale reddish brown.

Legs: dark brown to blackish, two yellowish brown rings near tips of femora.

Venter: ferruginous to black, spiracles surrounded with pale and appearing as white dots.

Records: ♀, Glacier, British Columbia. ♀ June 30, Utah, altitude 10,000 feet (United States National Museum). ♀ " Colo. 1699," received from C. P. Gillette under the name *Lygus robustus* Uhler.

This species is apparently known only from a few specimens, all of which came from high altitudes. The lack of material in the male sex prevents the figuring of genital claspers and therefore the placing of the species definitely in its proper group.

Lygus distinguendus var. **tahoensis** new variety

General aspect black mixed with brown, hemelytra with silvery gray sericeous pubescence grouped in small patches; differs from the above-described specimen of *distinguendus* from Glacier, British Columbia, in markings of head and pronotum and in having in general a darker color.

♀. Length 5.1 mm. *Head*: width across eyes 1 mm., vertex .43 mm., length of dorsal aspect .4 mm., height at base .57 mm.; basal carina rather sharp, flattened near eyes; black, a spot on each side of vertex next to eye joined by a marginal bar along front of eye, four or five transverse bars on either side of the black median line on the front, yellowish brown; dorsal margins of juga, dorsal half and anterior margin of each lora, pale to yellowish. *Rostrum* reaching to near posterior margins of middle coxae, yellowish brown to fuscous.

Antennae: segment I, length .34 mm., black, fuscous brown patch on lower side of apical half, very narrow ring at tip pale; II, 1.05 mm., dark fuscous grading into black at apex and base; III, .54 mm., black with a very narrow pale ring at base; IV, .43 mm., black; clothed with fine silvery pubescence, more noticeable on the last two segments.

Pronotum: length .91 mm., width at base 1.79 mm., width at anterior angles .91 mm., collar .63 mm.; dark brownish to fuscous and black; collar and five rays on disk dark yellowish brown, the median ray rather narrow and obsolete between calli, the ray on either side wider, crossing the inner angles of calli and turning along their anterior margins, the outside pair of rays less prominent and evident only behind calli; narrow margin at basal angles of disk pale, that part of the margin bordering the scutellum dark brown; side margins bordering the anterior coxae pale, but not extending up coxal cleft; calli distinct, more prominent than in *nubilus*; punctures rather fine and transversely confluent; pubescence silvery gray with some yellowish. *Scutellum* broad and flat, almost identical with *rubicundus* in this respect; transversely rugose, dark fuscous black, tip ivory white. *Sternum* black; narrow margins bordering the middle coxae, and posterior margin of metathoracic orifice, white.

Hemelytra: greatest width 2.16 mm.; brownish black, irrorate with patches of silvery gray sericeous pubescence with brownish pubescence between; tip of costal margin bordering the fracture pale; cuneus pale brownish, more or less translucent, apex and two basal angles dark fuscous; point of ivory-white at extreme tip of corium and adjacent to inner angles of cuneus, also pale on base of brachium. *Membrane* and veins brownish to fuscous, the part of the vein at the apex of the larger cell, the central part of the cells, a spot in the center of the membrane, and one on each side joining the margin, pale; margin of membrane bordering the dark tip of cuneus, clear.

Legs: coxae black, the apices and a part of the trochanters pale; a rather large and prominent puncture on the front side of the anterior coxae near base; femora dark brownish to black with two pale rings near apices, the ventral surfaces with one or two longitudinal pale bars; tibiae fuscous to black, a paler ring just below the knees and the inner surfaces light brownish for the most part; tarsi dark brownish, apices black.

Venter: black, a reddish shading along the vagina exterior and parts of the last two segments; spiracles surrounded by pale and appearing as pale spots.

Holotype: ♀ July 10, Angora Peak, Tahoe, California (E. P. Van Duzee).

This form is very close to *distinguendus*, and at present, with the lack of males to study, the writer prefers to place it as a variety of that species. The shape of the head, pronotum, and scutellum is suggestive of *rubicundus*, but the color, the larger size, and the more elongate form will at once distinguish the insect from that species.

Described from a unique female taken by Mr. Van Duzee, who lent the specimen for study. Until more material is available and the males are studied, the status of *distinguendus* and its varieties must remain incomplete.

Lygus robustus Uhler

1895 *Camptobrochis robustus* Uhler
Hemip. Colo., p. 39.

This species has been considered a Camptobrochis, but the description shows that Uhler undoubtedly had a Lygus before him when drawing the description. Mr. Van Duzee has taken a form of Lygus which agrees in many respects with the description of *robustus* yet does not appear to be typical of the species.

The original description reads as follows:

> " Short and thick, dusky testaceous, strongly marked with fuscous and black, coarsely, and in part densely punctate. Head almost vertical, vertex short, transversely grooved, bordered with a broken fulvous line in front, the occipital carina high, fitting into the collum, ivory yellow; front bordered with pale dull yellow, polished, remotely minutely obsolete-punctate and wrinkled, closely freckled with black, the inner border of the eyes also pale dull yellow, the lower part of tylus and the bucculae yellow; rostrum pale at base, piceous at tip, reaching to the middle coxae; antennae long and slender, as long as the corium and cuneus united, mostly pale fuscous, the basal joint dull pale fulvous, obscured with fuscous, the second very long, a little stouter than the third and fourth, slightly thicker towards the tip, the third and fourth together a little longer than the second, the fourth much the shortest. Pronotum convex, coarsely, deeply, irregularly punctate in somewhat transverse wavy lines, with about four obscure stripes which widen posteriorly, the lateral margins a little curved, the humeral angles broadly rounded, the posterior margin feebly curved and sinuated, and the anterior margin contracted and bordered with a somewhat pale collum, the callosities tumid, black, polished. Scutellum dark brown, closely and roughly wrinkled and unevenly punctate, convex,, olive-fulvous at tip. Legs pale olive-brownish, the femora piceous, rough at a few points, having one or more yellowish dots near the tip, the tibiae spotted with dark brown, closely pale pubescent, with the spines, tip of tarsi and nails dark piceous.

Clavus coarsely punctate and wrinkled, dark olivaceo-fuscous, corium a little paler, smoother, more finely punctate, almost bald, with the surface near the costa translucent, punctate with brown, the costal border dark brown, ending in a darker spot before the cuneus, the embolium broad and piceous black, the cuneus dark brown, bordered all around with pale testaceous; the membrane whitish, a little stained with brown at base and tip, and the veins mostly brown. Abdomen olivaceo-testaceous, finely pubescent, dusky at tip, with a line of black marks on the outer submargin, and a series of yellow dots on the connexivum.

" Length to end of abdomen 5 mm. To tip of membrane 6 mm. Width of pronotum 2.5 mm. Three or four specimens have been brought to my notice. One specimen from Colorado is chiefly dark fulvous, others were mostly chestnut brown or nearly black. The pale stripe with black arrest at the end of costal area will go far towards quickly distinguishing this species.

" North Park, July 20th (Gillette), and July 10th on *Artemisia tridentata* (Baker). Leadville, August 23d (Gillette). Cameron Pass, at 12,000 feet, on Salix (Baker)."

The following points show the species to be a Lygus and a member of the *pratensis* group: " antennae long and slender, as long as the corium and cuneus united, . . . Pronotum convex, coarsely, deeply, irregularly punctate in somewhat transverse wavy lines, with about four obscure stripes which widen posteriorly, . . . Scutellum dark brown, closely and roughly wrinkled and unevenly punctate, ..."

The types should be in the collection of the Agricultural Experiment Station at Fort Collins, Colorado, but have apparently become lost or mixed up with other material. The Uhler collection now in the United States National Museum contains no specimen bearing the label *Camptobrochis robustus*.

Lygus rubicundus Fallén

1829 *Phytocoris rubicundus* Fallén*
Hemip. Svec., p. 92.
1831 *Lygus rubricatus* Hahn
Wanz. Ins. 1:156, tab. xxiv, fig. 80.
1843 *Capsus rubricatus* Meyer-Dür*
Verzeich. Schweiz Rhyn., p. 73.
1846 *Miltemma rubricatus* Amyot
Soc. Ent. Fr., Ann. 4:151.
1848 *Capsus rubicundus* Sahlberg*
Mon. geoc. Fenn., p. 111.
1855 *Capsus* (*Deraeocoris*) *rubicundus* Kirschbaum*
Rhyn. Wiesb., p. 68, 113. (Separate.)
1858 *Deraeocoris rubicundus* Stål
Ent. Zeit. [Stettin] 19:186.
1858 *Hadrodema rubicunda* Fieber
Wien. Ent. Monatschr. 2:311, 345.
1860 *Capsus* (*Capsus*) *rubicundus* Flor*
Rhyn. Livl., p. 534.
1875 *Cyphodema* (*Agnocoris*) *rubicundum* Reuter
Hemip. gymn. Scand. et Fenn., p. 79.
1892 *Hadrodema pulverulenta* Uhler
Maryland Acad. Sci., Trans. 1892:183.
1896 *Lygus rubicundus* Reuter
Hemip. gymn. Eur. V, p. 72.

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*Reference given on the authority of Reuter.

Ovate, robust, dark reddish brown to fuscous; second antennal segment shorter than width of head; genital claspers very distinctive of the species.

♂. Length 4.5 mm. *Head*: width across eyes 1.04 mm., vertex .4 mm., length .43 mm., height at base .6 mm.; yellowish brown to reddish brown, marked with fuscous; basal carina scarcely raised from base of vertex, a slight depression each side of vertex at middle of eye; sutures about tylus and lorae, an area just above base of antenna, and usually a mark from each eye extending onto vertex and forward along median line of front, fuscous to blackish; eyes dark brownish. *Rostrum*, length 1.4 mm., reaching slightly beyond posterior margins of middle coxae, yellowish to brownish, apex fuscous.

Antennae: segment I, length .36 mm., brownish shaded with fuscous; II, 1 mm. (length less than width of head), yellowish brown, fuscous at base and apex; III, .45 mm., brownish tinged with fuscous, narrowly pale at base; IV, .4 mm., scarcely darker than segment III.

Pronotum: length 1.1 mm., width at base 1.88 mm., width at anterior angles .91 mm., collar .68 mm.; dark reddish brown shaded with fuscous; becoming fuscous first on the outer half of the calli, in the darkest specimens pale only on the collar, between the calli, and in a half-moon mark on the inner angles of the calli; extreme edge of the basal margin pale; side margins bordering the coxae pale, a fuscous mark across top of coxal cleft with a second just above and behind the top; punctures on the disk rather fine and closely placed, minute pale pubescence. *Scutellum* broad and rather flat, transversely rugose; dark brownish to fuscous, paler along the median line and lateral margins at base, extreme apex usually ivory-white. *Sternum* brownish to dark fuscous; pleura usually fuscous; margins of the sclerites paler; orifice pale.

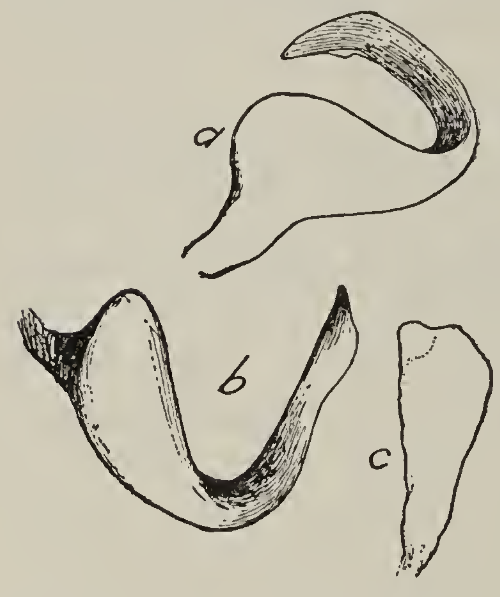

FIG. 175. LYGUS RUBICUNDUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Hemelytra: greatest width 2.14 mm.; very finely and closely punctured, pale pubescence closely appressed; dark yellowish brown to reddish brown, the darkest specimens fuscous to blackish, paler along the embolium and bases of corium and clavus; cuneus yellowish translucent, apex fuscous. *Membrane* fuscous, veins and a spot each side of the middle near the margin paler.

Legs: yellowish brown marked with fuscous; femora twice annulated near apices with fuscous, in some cases a broad band on the lower side near the middle; tibiae with a fuscous spot on the knees, a second ring or mark just below, spines reddish brown; tarsi yellowish to fuscous, apices darker.

Venter: reddish brown in certain forms, dark fuscous to blackish in others; beneath on first four segments, two stripes on sides, and surrounding spiracles, pale; genital claspers (fig. 175) very distinctive of the species, the right clasper without a claw.

♀. Very similar to the male in structure but usually not so darkly colored.

This species is common to both Europe and North America. Near Batavia, New York, the writer found it breeding on a species of willow (*Salix amygdaloides*), and apparently it occurs in scattering numbers on other willows. The nymphs are dull yellowish or cream-colored, and very robust in form. They appear on the host plant in June, the adults maturing early in July. Only one brood was observed to develop.

Records show that certain of the adults must hibernate but the number is apparently small.

Records: ♂ ♀ July 4, ♂ July 10, 45 ♂ ♀ July 19, ♂ July 22, Batavia, 2 ♂ 3 ♀ July 23, Ithaca, New York (H. H. Knight). ♀ May 16, Ithaca. 4 ♂ ♀ July 18, White Plains, New York (J. R. Torre Bueno). ♂ September 19, Bloomsburg, Pennsylvania (Wm. T. Davis). 15 ♂ ♀ May 16 to October 12, Plummers Island, ♂ June 20, Plum Point, Maryland (W. L. McAtee) ♂ ♀ July 23, El Paso, Texas; ♂ August 20, San Jacinto Peak, California, altitude 7000–10,000 feet; all collected by J. C. Bradley. ♂ July 28, Grand Junction, ♀ May 5, Fort Collins, ♀ July 16, Rocky Ford, Colorado (C. P. Gillette). 4 ♂ ♀ May 16, Ogden, Utah (A. Wetmore). 2 ♀ July 16, Fort Collins, Colorado; 2 ♂ July 4, Ottawa, Ontario, Canada; 3 ♀ April 12, San Diego County, California; all received from E. P. Van Duzee.

Lygus rubicundus var. **winnipegensis** new variety

Not structurally different from the typical *rubicundus*, but strikingly different in appearance, being almost entirely bright brick red in color.

♀. Length 4.3 mm., greatest width 2.16 mm. *Head*: width across eyes 1.03 mm., vertex .45 mm., length .43 mm., height at base .6 mm.

Antennae: segment I, length .31 mm.; II, .85 mm.; III, .43 mm.; IV, .37 mm.

Bright brick red, collar and between the calli paler, tip of the scutellum showing a small pale point; a translucent yellowish line bordering the exterior margin of the corium but not reaching the cuneus; tip of the tylus fuscous; tip and base of the second antennal segment darkened.

Holotype: ♀ bearing the label *May 7, 1910, Winnipeg, Manitoba* (*J. B. Wallis*), lent for study by E. P. Van Duzee.

A specimen from Fort Collins, Colorado, approaches this color variety but is not so bright red as the type.

Lygus sallei Stål

1862 *Lygus sallei* Stål
Ent. Zeit. [Stettin] 23:321.

Broad ovate, the males more elongate; dull yellowish or bright green, glabrous, shining; genital claspers distinctive of the species.

♂. Length 5.9 mm. (variation 4.8–6 mm.). *Head*: width across eyes 1.18 mm., vertex .45 mm., length .51 mm., height at base .63 mm.; smooth shining, dull yellowish to bright green; eyes dark brown to black, collum black. *Rostrum*, length 2.42 mm., scarcely reaching posterior margins of hind coxae, yellowish, apex fuscous.

Antennae: segment I, length .63 mm., greenish yellow; II, 1.45 mm., yellowish, apical half more brownish; III, .85 mm., brownish to pale fuscous; IV, .57 mm., slightly darker than segment III.

Pronotum: length 1.18 mm., width at base 2.2 mm., width at anterior angles 1.17 mm., collar .77 mm.; broad with disk flattened, side margins acute; glabrous, smooth shining, punctures fine but distinct; dull yellowish to bright green, anterior margin behind the collar, and usually the lateral and basal margins of the disk, narrowly blackish; extreme basal edge of disk pale. *Scutellum* rather broad and flat, shining, finely punctured, transversely rugulose; dull yellowish to bright green, in some cases marked with fuscous at middle of base and each side near apex. *Sternum* and pleura dull yellowish or tinged with green.

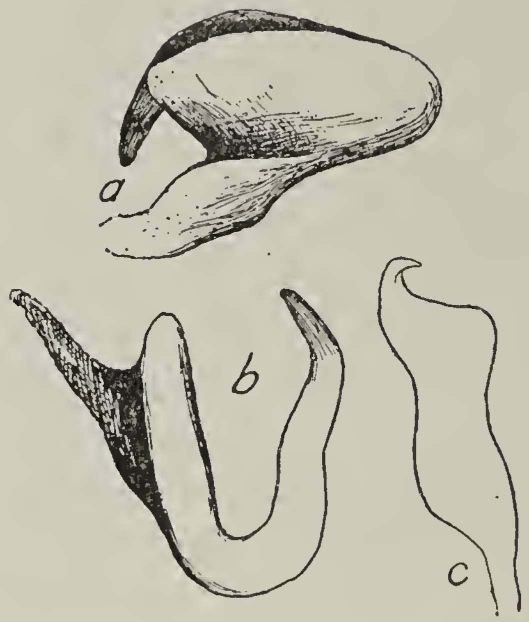

FIG. 176. LYGUS SALLEI, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Hemelytra: greatest width 2.68 mm.; dull yellowish to bright green, translucent; glabrous, punctures distinct and closely placed. *Membrane* clear, shaded with fuliginous in the middle and toward the apex; a dark brownish to fuscous mark at the inner apical angles of the brachium, similar to that in *aeratus* and *humeralis*; veins yellowish or bright green.

Legs: dull yellowish to greenish; dark specimens have the posterior femora twice annulated with fuscous near the apices, tibiae unusually thick, spines brownish and frequently fuscous at base.

Venter: yellowish to bright green, sides with a brownish stripe; genital claspers (fig. 176) distinctive of the species.

♀. Length 5.8 mm., greatest width 2.65 mm.; more robust than the male but not differing in coloration.

In California Mr. Van Duzee finds this species living on *Bassaris* sp.

Records: ♀ July 23, Palmer Lake, Colorado. 8 ♂ ♀ July 29, Huachuca Mountains, Arizona, altitude 9000 feet (H. G. Barber). 7 ♂ ♀ Little Spring, San Francisco Mountain, Arizona (A. K. Fisher). ♂ ♀ June 17, Cloudcroft, New Mexico. ♂ ♀ May 13, San Francisco, ♂ ♀ Los Angeles County, ♂ ♀ April, June, San Diego County, California (E. P. Van Duzee). Some of the California specimens are smaller and darker-colored than the typical form.

Lygus campestris Linnaeus

1758 *Cimex campestris* Linnaeus
Syst. nat., 10th ed., p. 448.
1787 *Cimex transversalis* Fabricius
Mant. ins. 1:304.
1794 *Lygaeus campestris* Fabricius
Ent. syst. 4:171.
1794 *Lygaeus transversalis* Fabricius
Ent. syst. 4:175.
1804 *Miris campestris* Latreille
Hist. nat. 12:221.
1804 *Miris transversalis* Latreille
Hist. nat. 12:225.
1807 *Lygaeus pastinacae* Fallén
Mon. cim. Svec., p. 86.
1829 *Phytocoris pastinacae* Fallén
Hemip. Svec., p. 94.
1848 *Capsus pastinacae* Sahlberg
Mon. geoc. Fenn., p. 113.

1855 *Capsus lucidus* Kirschbaum (see Reuter, 1888)
Rhyn. Wiesb., p. 68, 131. (Separate.)
1858 *Deraeocoris pastinacae* Stål
Ent. Zeit. [Stettin] **19**:186.
1858 *Orthops pastinacae* Fieber
Wien. Ent. Monatschr. 2:345.
1871 *Capsus transversus* Thomson
Opuscula ent. **4**:427.
1875 *Lygus* (*Orthops*) *transversalis* Reuter
Rev. crit. Caps., p. 59. (Separate.)
1875 *Lygus* (*Orthops*) *pastinacae* Puton
Cat. Hémip., p. 36.
1875 *Lygus pastinacae* Saunders
Ent. Soc. London, Trans. **1875**:275.
1877 *Orthops scutellatus* Uhler
U. S. Geol. and Geog. Surv., Terr. 3, Bul. 2:420.
1888 *Lygus* (*Orthops*) *campestris* Reuter
Revis. synon., p. 641.
1896 *Lygus campestris* Reuter
Hemip. gymn. Eur. V, p. 79.

Ovate, rather small, greenish brown or brownish yellow with fuscous, scutellum bright yellow or green; genital claspers distinctive of the species.

♂. Length 4.1 mm. *Head*: width across eyes .83 mm., vertex .36 mm., length .34 mm., height at base .48 mm.; carina prominent, transverse, slightly indented just in front; yellowish brown; apical half of tylus, lower half of juga, gula, and bases of bucculae, fuscous; eyes dark brown, collum black. *Rostrum*, length 1.34 mm., just attaining posterior margins of middle coxae, yellowish brown, apex fuscous.

Antennae: segment I, length .31 mm., dark brownish; II, 1.03 mm., dark brownish; III, .48 mm., dark fuscous brown; IV, .4 mm., scarcely darker than segment III; thickly clothed with prominent pale yellowish pubescence.

Pronotum: length .84 mm., width at base 1.48 mm., width at anterior angles .71 mm., collar .83 mm.; closely and distinctly punctured, rather long fine pale pubescence; yellowish brown darkened with fuscous, in some cases with greenish; posterior half of calli, basal angles and usually more extensively across the base of the disk, above the coxal cleft and extending in a ray behind, fuscous to blackish. *Scutellum* bright yellow or more rarely bright green, in some cases blackish in the middle at the base thus making the yellow color heart-shaped; fine pale pubescence, transversely rugulose; mesoscutum always dark brownish to blackish. *Sternum* fuscous, opaque, usually with a brownish patch at the sides; pleura fuscous; margins of the sclerites usually brownish; orifice pale.

Hemelytra: greatest width 1.77 mm.; dark yellowish to fuscous brown; clavus and apex of corium more fuscous; embolium frequently with green, extreme outer edge fuscous; cuneus dull yellowish or greenish, the apex and extending back along the inner margin fuscous. *Membrane* pale, more or less tinged with pale fuscous or fuliginous.

Legs: yellowish or greenish yellow; posterior femora usually twice annulated near apices with fuscous, frequently indistinct on the upper side; tibial spines dark brownish to black; apices of tarsi blackish.

Venter: yellowish or greenish yellow; genital segment and a broad band along the dorso-lateral margin fuscous to blackish; genital claspers (fig. 177) distinctive of the species.

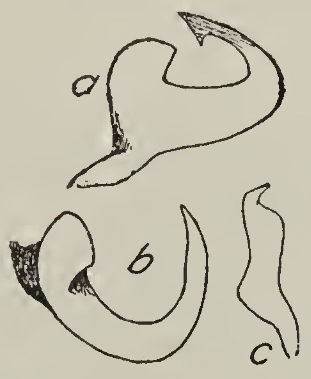

Fig. 177. LYGUS CAMPESTRIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

♀. Slightly more robust than the male, second antennal segment more slender than in the male; very similar to the male in coloration.

This species is common to Europe and North America, breeding on plants of the family Umbelliferae. In western New York the writer found the species breeding most abundantly on poison hemlock (*Conium maculatum*). In one case at least the species is reported as destructive to a cultivated crop, at Flatlands, New Brunswick, where the insects were sufficiently abundant to cause the death of celery plants. This record is doubtless authentic, for specimens were determined by Mr. Heidemann, the data being here given thru the courtesy of Mr. Arthur Gibson, of the Entomological Branch, Ottawa, Canada.

The species hibernates in the adult state and in New York comes forth on the host plant early in May. On May 25, 1916, the writer took a large series of the overwintering individuals which had collected on poison hemlock for feeding and egg-laying. The nymphs were developing on the host plant early in July, and on July 30 a large series of freshly emerged adults were taken. The adults continue feeding on the host plants until early September, when they retreat for hibernation.

Records: ♂ ♀ May 25 to August 19, Batavia, 2 ♂ 2 ♀ July 26, Ithaca, New York (H. H. Knight). ♀ February 23 (under pine bark), Eastern Branch near Bennings, District of Columbia (W. L. McAtee). ♂ June 28, St. Johnsbury, Vermont, ♂ August 19, Fort Kent, Maine (C. W. Johnson). ♂ ♀ August 12, Truro, Nova Scotia (R. Matheson). 4 ♂ ♀ July 18–23, Truro, Nova Scotia (William H. Brittain). 4 ♂ ♀ Spruce Brook, Newfoundland (Charles Schaeffer). ♂ ♀ August 7–11, Goldstream to Downie Creek, British Columbia (J. C. Bradley) ♂ ♀ July 17, Tallac, Lake Tahoe, California (E. P. Van Duzee).

Lygus distinctus new species

Very distinct in coloration and in form of the genital claspers; pale marked with purplish red and fuscous, stricture of the collar and margins of the calli exhibiting the darkest color.

♂. Length 4.6 mm. *Head*: width across eyes 1 mm., vertex .35 mm., length .38 mm., height at base .57 mm.; strongly vertical, smooth shining, carina slightly sinuate; pale, front marked with dark brownish each side of median line, a distinct spot each side of vertex; sutures about juga and lorae purplish red, tylus marked with dark brown and reddish; eyes dull brown, each facet showing dark reddish. *Rostrum*, length 1.31 mm., scarcely attaining posterior margins of middle coxae, pale to yellowish brown, apex scarcely darker.

Antennae: segment I, length .45 mm.; pale, darkened with fuscous on the lower side; II, 1.48 mm., yellowish brown, fuscous near the base, apical one-third fuscous with reddish; III, .57 mm., reddish brown tinged with fuscous; IV, .4 mm., scarcely darker than segment III.

Pronotum: length .97 mm., width at base 1.74 mm., width at anterior angles .8 mm., not sharply defined; collar .62 mm.; pale, shaded with fuscous across base of disk, divided in the middle by a pale median line, extreme edge of basal margin white; stricture of the collar, anterior half of the calli, a heavy line along the posterior margins of the calli and terminating at the outer angles in a short recurved hook, dark purplish brown to blackish; side margins behind coxal cleft shaded with fuscous and in some cases flecked with reddish; irregularly punctate, the heaviest punctures grouped in the center of the disk, fine yellowish pubescence. *Scutellum* purplish red, a median pale vitta on the apical half, joined at base by an irregular pale area occupying the basal angles; transversely rugose but not distinctly punctate, shining. *Sternum* yellowish with pale, the sides irregularly flecked with reddish; pleura reddish flecked with pale; orifice pale.

Hemelytra: greatest width 1.88 mm.; purplish red marked with pale; claval vein, brachium, cubitus, and most of embolium, pale; middle of clavus and a spot toward the apex, and an irregular area across the corium just before the middle, paler; cuneus pale, translucent, apex darkened with reddish brown tending to spread along the inner margin and flecked with red; punctures indistinct, shining, very fine pale pubescence. *Membrane* clear, veins reddish, a fuscous mark at the inner apical angles of the brachium as noted in *aeratus* and *humeralis*.

Legs: yellowish, femora irregularly annulated near the apices with two bands of reddish patches and spots; tibial spines dark brownish, fuscous at base; apices of tibiae and tarsi brownish.

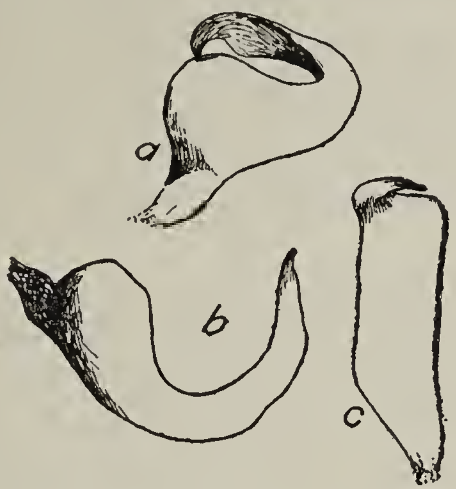

Fig. 178. LYGUS DISTINCTUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Venter: pale, sides and genital segment purplish red; genital claspers (fig. 178) distinctive of the species.

Holotype: ♂ June 19, Prescott, Arizona.

This species doubtless belongs to the Lower Sonoran fauna and will be found more extensively in Mexico, but the writer is unable to find anything in the *Biologia* by Distant that answers to the description of the species.

Lygus pabulinus Linnaeus

1761 *Cimex pabulinus* Linnaeus
Fauna Svec., 2d ed., p. 253.
1783 *Cimex nigrophthalmus* Retzius
De Geer gen. et spec., p. 87.
1785 (?) *Cimex aerugineus* Fourcroy
Ent. par. 1:208.
1794 *Miris pabulinus* Fabricius
Ent. syst. 4:184.
1807 *Lygaeus pabulinus* Fallén
Mon. cim. Svec., p. 75.
1813 *Cimex hortorum* Tigny
Hist. nat. ins. 4:287.
1828 *Phytocoris pabulinus* Zetterstedt
Fauna ins. lapp., p. 468.
1831 *Lygus pabulinus* Hahn
Wanz. Ins. 1:148, fig. 74.
1843 *Capsus affinis* Meyer-Dür
Verzeich. Schweiz Rhyn., p. 48, tab. I, fig. 3. (Not Herrich-Schaeffer.)
1848 *Capsus pabulinus* Sahlberg
Mon. geoc. Fenn., p. 101.

1855 *Capsus (Deraeocoris) pabulinus* Kirschbaum
Rhyn. Wiesb., p. 57. (Separate.)
1860 *Lygus solani* Curtis
Farm insects, p. 434, fig. 59, no. 20, and Pl. O, figs. 20, 21.
1861 *Lygus flavovirens* Fieber
Eur. Hemip., p. 276.
1861 *Lygus chloris* Fieber
Eur. Hemip., p. 276.
1875 *Lygus (Lygocoris) pabulinus* Reuter
Hemip. gymn. Scand. et Fenn., p. 61.
1875 *Lygus (Lygocoris) flavovirens* Reuter
Hemip. gymn. Scand. et Fenn., p. 62.
1903 *Lygus chagnoni* Stevenson
Can. ent. 35:214.
1909 *Lygus pabulinus* var. *signifer* Reuter
Bemerk. neark. Caps., p. 42.

Elongate, pale green or greenish yellow frequently fading to dull yellowish, carina of vertex obsolete in the middle; a fuscous Y-shaped mark formed at the extreme basal angle of the membrane, and usually a spot within the apices of the cells and a distinct longitudinal cloud extending beyond to the tip of the membrane.

♂. Length 5.5 mm. *Head*: width across eyes .94 mm., vertex .37 mm., length .4 mm., height at base .56 mm.; greenish yellow or frequently entirely dull yellow, pubescent, shining, eyes dark brown or black; carina obsolete in the middle and apparent only at the corners of the eyes, from which an impressed line extends to near the center of the vertex. *Rostrum*, length 2.08 mm., attaining posterior margins of hind coxae, greenish yellow to brownish, darker toward the apex.

Antennae: segment I, length .68 mm., greenish yellow or bright green, paler at base, lower apical half frequently darkened with fuscous; II, 2.2 mm., apical half dark fuscous to blackish, basal part greenish to yellowish brown and shading into the darker; III, 1.34 mm., blackish; IV, .85 mm., black; segments clothed with very fine pale pubescence, segment I with darker.

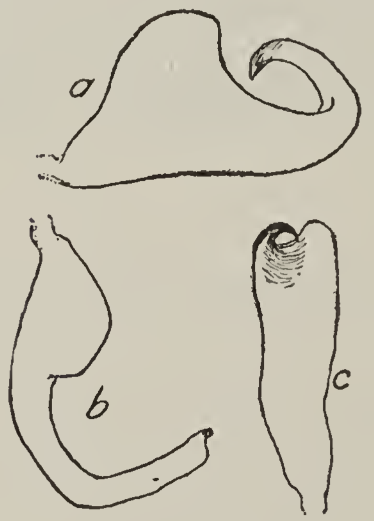

FIG. 179. LYGUS PABULINUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

Pronotum: length 1.03 mm., width at base 1.72 mm., width at anterior angles .77 mm., collar .6 mm.; bright green to yellowish green, before the calli often strongly yellow, punctures of disk fine and closely placed, more or less transversely confluent on the basal half, moderately clothed with pale yellowish pubescence. *Scutellum* green to yellowish green, pubescent, transversely wrinkled near middle, punctures indistinct. *Sternum* green or yellowish.

Hemelytra: width 2 mm., green or faded to greenish yellow, finely and shallowly punctured, clothed with fine pale yellowish pubescence. *Membrane* pale, marked with fuscous, iridescent; extreme basal angles dark brown to blackish forming a Y-shaped mark, the base of which lies between the inner apical angles of the corium; a fuscous spot within the apex of each cell; a curved streak extending from the margin at a point just beyond the apex of the cuneus, inward to opposite the large cells, then as a more or less longitudinal cloud to the tip of the membrane, thus leaving a large pale spot in the center.

Legs: greenish yellow, apices of the tibiae and spines brownish, tarsi brownish with the apical segments black, claws brownish.

Venter: green or faded to yellowish; genital claspers (fig. 179) characteristic of the species.

♀. Length 6.1 mm., width 2.22 mm.; slightly larger and more robust than the male but not differing in coloration.

The species is of frequent occurrence in North America and does not differ in any respect from European specimens that the writer has studied, two of which were dissected for genital characters.

In western New York the species breeds on the spotted touch-me-not (*Impatiens biflora*), growing in damp, cool situations. Nymphs were found on June 22, when the first adult was taken, and on June 27 adults were maturing rapidly. Nymphs were taken on the host plant as late as August 26 and the last adult was found on October 16. In coloration the nymphs are pale green with whitish on the wing pads, which coloration makes them blend well with the host plant.

Reuter (1909) records the species as hibernating in Finland, while C. R. Crosby took a female specimen from beneath the bark on a tree on November 14, as recorded below. It is very probable that the species also passes the winter in the egg stage on the dried stems of the host plant. The specimens taken on Whiteface Mountain on August 22 were all found on *Diapensia lapponica*, which was in bloom at that time.

Records: ♀ June 22, 32 ♂ ♀ June 27, Portage, 3 ♂ 3 ♀ June 26, ♀ July 5, ♂ July 8, 33 ♂ ♀ July 31 to August 31, Batavia, ♀ 4 ♂ July 4, Four Mile, 75 ♂ ♀ July 24–26, Ithaca, ♂ July 27, McLean, ♀ October 16, White Plains, 59 ♂ ♀ August 22, Whiteface Mountain, New York; all collected by the writer. ♀ 3 ♂ June 21, Ridgewood, New Jersey (M. D. Leonard). ♀ November 14, 1915, Howlands Island, Cayuga County, New York (C. R. Crosby); collected from under bark, where it was evidently in hibernation. ♂ ♀ Flushing, Long Island, ♂ Johnstown, New York (Wm. T. Davis). ♂, Mount Katahdin, Maine (H. G. Barber). 4 ♀ August, Black Mountains, North Carolina (Beutenmuller). 6 ♂ ♀ June 8, Plummers Island, Maryland, ♂ May 31, Four Mile Run, Virginia, ♂ ♀ June 7, District of Columbia (W. L. McAtee). ♂, Aurora, West Virginia (O. Heidemann). 27 ♂ ♀ August 7–11, Goldstream to Downie Creek, Selkirk Mountains, British Columbia (J. C. Bradley).

Reuter (1909) described the variety *signifer* as a form distinguished chiefly by the longitudinal fuscous marks on the membrane. The same author (1896) described the typical species with similar marks on the membrane. The present writer has been unable to draw varietal distinctions between the North American *pabulinus* and the specimens from Europe.

Lygus approximatus Stål

1858 *Deraeocoris approximatus* Stål
Ent. Zeit. [Stettin] 19:185.
1879 *Lygus approximatus* Reuter
Öfv. Finska Vetensk. Soc., Förh. 21:53. (Separate.)

Male very slender, nearly black, with the collar and the tip of the scutellum white. Female usually reddish with fuliginous on the pronotum, in some cases nearly as dark-colored as the male.

♂. Length 4.9 mm. *Head:* width across eyes .91 mm., vertex .34 mm., length .4 mm., height at base .56 mm., distance from top of eyes to tip of tylus .74 mm.; black, shining, eyes dark reddish brown; head greatly produced as compared with other species of Lygus; carina prominent, nearly straight, vertex with an impressed triangle just in front; fine pale pubescence. *Rostrum,* length 2.45 mm., reaching to middle of venter; yellowish brown, apex blackish.

Antennae: segment I, length .48 mm., yellowish green, base slightly infuscated, pubescence blackish; II, 1.77 mm., greenish yellow to brownish and blackish, pubescence pale; III, .91 mm., fuscous, greenish at base; IV, .6 mm., fuscous.

Pronotum: length .8 mm., width at base 1.42 mm., width at anterior angles .68 mm., collar .57 mm.; black, shining, collar white, narrow basal margin of disk usually pale; lower side margins bordering the coxae pale; punctures shallow, distinct, not so closely placed as in *communis* and related species; pubescence brownish. *Scutellum* black, shining, in some cases brownish at the sides, apex white; rather coarsely transversely rugose on the basal half; pale pubescent. *Sternum* black, alutaceous; pleura blackish; sutures between, narrow margin bordering the coxae, and orifice, white. An unusual color form of the male has the pronotum mostly reddish, like that of the typical female.

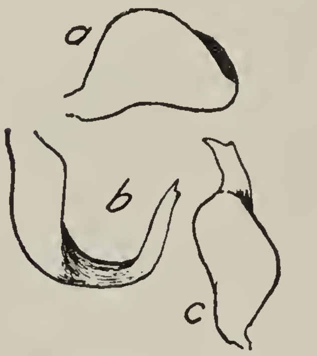

FIG. 180. LYGUS APPROXIMATUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, external lateral aspect

Hemelytra: greatest width 1.82 mm.; brownish black to blackish, tips of the embolium and cuneus reddish brown, inner basal angle of the cuneus pale; minutely punctured, more or less scabrous, prominent yellowish pubescence. *Membrane* fuscous; basal half of the large cells, bordering the apex of the cuneus, a small spot joining the margin just beyond the apex of the cuneus, pale; veins reddish; cuneus and membrane only slightly deflected downward, thus giving the appearance of an Orthotylus.

Legs: coxae pale yellowish, in some cases much darkened with fuscous; femora yellowish green, paler at the base, the hind pair usually darkened with fuscous or frequently dark reddish brown; tibiae greenish, in some cases tinged with fuscous, spines black, on the hind pair greater in length than the thickness of the tibia; apices of tarsi blackish, claws brownish.

Venter: black, more or less shining, frequently the lower side pale greenish; genital claspers (fig. 180) distinctive of the species. The male claspers, as well as other characters, show this to be one of the aberrant forms included in the genus Lygus. This species and *rubricatus* Fallén might well be given subgeneric rank if we recognize any subgenera in Lygus.

♀. Length 4.9 mm., width 1.82 mm.; more robust than the male, the reddish colors making it appear quite different from the male; head longer (.48 mm.) and less vertical than in the male; rostrum (length 2.57 mm.) attaining the middle of the venter.

Dark reddish to brownish with fuliginous; tylus black, frequently darkened over the whole front; pronotum darkened with fuliginous on the base and along the lateral margins of the disk, in some forms much darker, in the darkest unusual forms the whole pronotum may be nearly black as in the male; collar and tip of scutellum white, very narrow basal margin of the disk pale; sternum and pleura mostly fuliginous; venter, hind femora, and often the intermediate femora, strongly reddish.

This species has a very different aspect from the usual forms of Lygus. It is very similar to the European *Lygus rubricatus* Fallén, but differs at least in being larger. The male is suggestive of an Orthotylus or a very large Plagiognathus. The head is long and projects downward farther than in other species of Lygus, the rostrum reaching to the middle of the venter.

The species was originally described from Sitka, Alaska, and appears to be distributed thruout the mountainous regions of the northern United States and Canada.

Records: 17 ♂ 9 ♀ August 22, Whiteface Mountain, New York; all the specimens collected by the writer from *Solidago macrophylla*, which was found growing abundantly near the top of the mountain. At that season it was too late to determine whether or not the nymphs had developed on the plant.

3 ♀ July, Parry Sound, Ontario, Canada (H. S. Parish). ♀ September 18, Randolph, ♀ Mount Washington, New Hampshire (Wm. T. Davis). ♂ July 26, Truro, Nova Scotia (R. Matheson); this specimen mostly reddish, like the typical female. 3 ♀ August, Mount Katahdin, Maine, ♀ August 29, Cascade Lake, Adirondack Mountains, New York (H. G. Barber). ♀ Mount Washington, New Hampshire (Mrs. A. T. Slosson). ♂ July 20–22, Big Bend Country, Selkirk Mountains, British Columbia (J. C. Bradley).

Lygus olivaceus Reuter

1907 *Lygus olivaceus* Reuter
Öfv. Finska Vetensk. Soc., Förh. 49^5:6.

Small, oval, greenish yellow marked with reddish and brown; eyes large, the head unusually broad for the size of the insect; scutellum, inner half of the clavus, inner apical angles of the corium, reddish brown to fuscous; genital claspers distinctive of the species.

♂. Length 3.6 mm. *Head*: width across eyes .98 mm., vertex .28 mm., length .32 mm., height at base .51 mm.; short and broad, strongly compressed, eyes very large, carina scarcely raised from basal margin of vertex; greenish yellow, in some cases marked with reddish on the front and the lorae, eyes dark brown. *Rostrum*, length 1.42 mm., scarcely attaining posterior margins of hind coxae, greenish yellow, apex fuscous.

Antennae: segment I, length .4 mm., greenish yellow; II, 1.4 mm., yellowish brown, apex fuscous; III, .63 mm., pale yellowish tinged with fuscous on the apical half; IV, .45 mm., fuscous.

Pronotum: length .8 mm., width at base 1.42 mm., width at anterior angles .65 mm., collar .54 mm.; greenish yellow or olive green; very minutely punctured, fine pale yellowish pubescence. *Scutellum* dark reddish or with fuscous, apex more or less pale; minutely transversely rugulose, pale pubescent. *Sternum* pale yellowish, sides darkened with fuscous; pleura dark brownish to fuscous, margins paler; orifice pale.

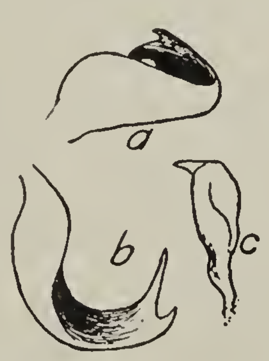

FIG. 181. LYGUS OLIVACEUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Hemelytra: greatest width 1.6 mm., minutely punctured, pale yellowish pubescence; greenish yellow darkened with brownish and reddish; inner half of the clavus bordering the scutellum dark brownish to fuscous; inner apical angles of the corium darkened with fuscous, in some cases showing reddish; cuneus pale yellowish, apex dark reddish to black. *Membrane* fuscous, a spot each side near the margin, and a narrow margin bordering the cuneus, pale; some specimens with the membrane much paler.

Legs: yellowish or greenish yellow; posterior femora with two fuscous or reddish rings near the apices, extreme apex also fuscous; tibiae yellowish, spines scarcely darker; tarsi with the apices fuscous.

Venter: yellowish, in some cases marked with reddish or brownish on the sides; genital claspers (fig. 181) distinctive of the species.

♀. Slightly larger and more robust than the male; the northern specimens lack the fuscous on the apex of the second antennal segment, and are more reddish and have the membrane paler than those coming from Florida.

Description drawn from specimens collected by E. P. Van Duzee in April, 1908, at Crescent City, Florida. The species was originally described from material collected by Mr. Van Duzee in Jamaica. The writer has not seen the types, but the specimens coming from the Southern States are doubtless identical with the material described by Reuter.

Records: Several specimens, April, 1908, Crescent City, Florida (E. P. Van Duzee). ♂ ♀ Opelousas, Louisiana (G. R. Pilate). ♀ September 13, Manasquan, New Jersey (Wm. T. Davis). ♂ ♀ Bayville, New York (N. Banks); taken on *Baccharis halimifolia*, which may possibly be the host plant. ♂ ♀ September 7, East River, Connecticut (C. R. Ely). ♂ August 8, Manomet, Massachusetts.

Lygus olivaceus var. **viridiusculus** new variety

Structurally not distinguishable from the *olivaceus* described above; bright green, slightly larger than and lacking the brownish and fuscous coloring of *olivaceus*.

♀. Length 4.6 mm. *Head*: width across eyes 1.05 mm., vertex .38 mm., length .37 mm., height at base .6 mm.; carina scarcely raised from the vertex; greenish yellow, a touch of red on the lorae, eyes dark brown. *Rostrum*, length 1.57 mm., reaching to near posterior margins of hind coxae, yellowish, apex fuscous.

Antennae: segment I, length .4 mm., green; II, 1.37 mm., greenish yellow, more brownish toward the apex; III, .77 mm., yellowish; IV, .51 mm., greenish yellow tinged with fuscous.

Pronotum: length .97 mm., width at base 1.65 mm., width at anterior angles .8 mm., collar .6 mm.; bright green; minutely punctured as in *olivaceus*. *Scutellum* bright green with a touch of red on the side margins. *Sternum* green; pleura and orifice greenish.

Hemelytra: greatest width 2.05 mm.; bright green, a touch of fuscous at the extreme tip of the corium and nearest the membrane; clavus only slightly tinged with fuscous near tip of scutellum; cuneus greenish yellow, extreme apex blood red. *Membrane* pale, shaded with fuliginous within apices of cells, a spot near the tip of the cuneus, and to a less extent thru the middle and toward the tip of the membrane.

Legs: greenish yellow; posterior femora with two red marks on the upper side near the apices; tibiae reddish on the inside at the base; tips of tarsi brownish.

Venter: bright green.

Holotype: ♀ August 5, Tisbury, Massachusetts (Cushman).
Paratypes: ♀, topotypic.

Lygus fasciatus Reuter

1876 *Lygus fasciatus* Reuter
Caps. Amer. bor., p. 72.

The following is a liberal translation from the original latin description:

"Greenish testaceous, very finely punctate above, second antennal segment shorter than the basal margin of the pronotum; scutellum with lateral vittae, clavus inwardly, and apex of corium broadly transversely brownish, apex of cuneus black; femora twice annulated near the apices and tibiae annulated at the bases with ferruginous; apices of the tarsi fuscous; tibiae impunctate, spines testaceous. Length 4.75 mm. 'Hab. Carolinam meridionalem.' "

The size and the color characters, combined with the fact that the second antennal segment is shorter than the basal margin of the pronotum, should be sufficient to distinguish the species. The writer ventures to suggest that the type of this species will turn out to be a female of *olivaceus*. The combination of size and coloration, particularly that given for the scutellum and the clavus, with the tibiae "annulo basali ferrugineo," are characters found thus far only in certain female forms of *olivaceus*.

The type of this and other Reuter species are probably still to be found in the National Museum at Stockholm.

Lygus apicalis Fieber

1861 *Lygus apicalis* Fieber
Eur. Hemip., p. 275.
1870 *Lygus putoni* Meyer-Dür
Schweiz. Ent. Gesell., Mitt. 3:207.
1876 *Lygus prasinus* Reuter
Caps. Amer. bor., p. 71.
1894 *Lygus apicalis* var. *inops* Horváth
Rev. d'ent. 8:190.
1909 *Lygus apicalis* var. *prasinus* Reuter
Bemerk. neark. Caps., p. 43.

Male oblong, female more ovate; greenish, dark green, or yellowish green, the membrane, and in some cases the corium, marked with fuscous; head broad, the eyes unusually large in the male; genital claspers very distinctive of the species.

♂. Length 4.5–5 mm. *Head*: width across eyes 1.12 mm., vertex .29 mm., length .41 mm., height at base .65 mm.; greenish yellow, eyes brownish; eyes unusually large; vertex narrow; carina thick, arcuate. *Rostrum*, length 1.97 mm., reaching slightly beyond posterior margins of hind coxae, yellowish green, apex blackish.

Antennae: segment I, length .51 mm., greenish; II, 2.05 mm., yellowish tinged with brownish; III, 1 mm., dark yellowish; IV, .63 mm., slightly darker than segment III.

Pronotum: length .88 mm., width at base 1.65 mm., width at anterior angles .8 mm., collar .65 mm.; green, becoming yellowish in front and on lower side margins; calli smooth and indistinct; shallowly and finely punctate, more or less transversely confluent, fine yellowish pubescence. *Scutellum* green or tinged with yellowish, darkest forms marked with fuscous on the base; very finely transversely rugose, pale pubescence. *Sternum* and pleura yellowish; orifice paler.

Hemelytra: greatest width 2 mm.; dark green to yellowish, in dark forms the clavus and the corium marked with fuscous; cuneus greenish, apex blackish; minutely and shallowly punctate, pale pubescence. *Membrane* fuscous marked with pale; usually paler in the middle, basal half of the cells, veins, and bordering the cuneus, also a paler spot near the margin beyond the apex of the cuneus.

Legs: greenish or yellowish green; posterior femora indistinctly twice annulated with fuscous near the apices; tibiae green, spines brownish; tips of tarsi fuscous.

Venter: greenish, usually a narrow fuscous line on the sides; genital claspers very distinctive of the species, the sinistral clasper very complicated (fig. 182).

♀. Length 4.6 mm., width 2.05 mm., width of head 1.05 mm., vertex .37 mm.; uniformly green or greenish yellow; eyes dark brown; tips of tarsi and apex of rostrum blackish.

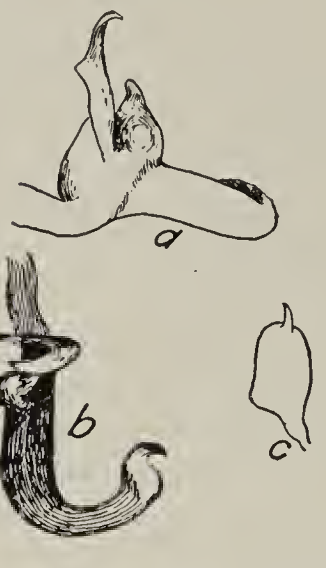

FIG. 182. LYGUS APICALIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, internal lateral aspect

This species is most abundant in the Southern States, from Florida to Texas, but occurs northward along the Atlantic coast as far as Maine. This is doubtless the species that has in the past been responsible for the records in literature of the occurrence in the United States of *L. contaminatus* Fallén and *L. lucorum* Meyer-Dür. The writer has studied European forms of those species which were determined by Reuter and sent over to the United States National Museum, and wishes to state that he has not yet seen a specimen of either *contaminatus* Fallén or *lucorum* Meyer-Dür collected in America.

Among the determined species of Lygus sent over by Reuter there were only females of *apicalis*, and thus the writer has been unable to compare the male genitalia with the American forms of *apicalis*. These European female specimens of *apicalis* appear to be identical with the American forms, but the ultimate decision rests in the comparison of the genital claspers, which in this case are very complicated and therefore distinctive.

Reuter (1909) reduces his *prasinus* (1876) to a variety of *apicalis* Fieber. The uniformly green specimens show a gradual change into those having pale fuscous on the hemelytra and the scutellum, and even the fuscous forms are so pale that there appears to be no need of trying to use the varietal name. The European female specimens studied are uniformly greenish, like the American forms.

The writer received dark green California specimens from Mr. Van Duzee, which he took to be *L. contaminatus* Fallén, but the genital claspers are identical with those of our eastern *apicalis* (fig. 182). Specimens coming from Mexico are larger than our northern forms, but here again the distinctive claspers determine the species.

In Missouri the writer took specimens of *apicalis* on weeds and grasses, but was unable to determine a definite host plant.

Records: ♀ September 6, Liberty, Maine (Cushman). ♀ August 22, Edgartown, Massachusetts. ♀ October 12, Washington, D. C. (O. Heidemann). ♂ September 20, Lake Waccamaw, 4 ♂ ♀ September 21, Boardman, North Carolina (R. W. Leiby). ♂ September, Jefferson, North Carolina (F. Sherman). ♂ 2 ♀ July 1, Billy Island, Okefenokee Swamp, Georgia (J. C. Bradley). ♀ October 16, Tifton, Georgia. ♀, Alabama. 5 ♀ October 23–30, Dunedin, Florida (W. S. Blatchley). ♂ ♀ November 19, Newberry, ♀ November 3, Jacksonville, Florida (Wm. T. Davis). ♂ ♀, Biscayne Bay, Florida (Mrs. A. T. Slosson). 2 ♀ May 8, Natchitoches Parish, Louisiana (K. P. Schmidt). ♂ Brazos County, Texas (N. Banks). 3 ♂ July 18, Springfield, 3 ♂ 2 ♀ Hollister, Missouri (H. H. Knight). ♂ July 24, Apalachicola, Florida. 2 ♂ October 5, Plummers Island, Maryland (W. L. McAtee). ♂ April 29, ♂ May 1, ♂ May 24, ♂ June 6, ♂ ♀ June 30, ♂ October 4, 2 ♂ December 25, San Diego County, California; 2 ♂ 2 ♀ April 26, Sanford, Florida; all collected by E. P. Van Duzee.

Lygus fagi new species

In general appearance very similar to *hirticulus*, but the males differ greatly in the genital claspers. In this species the male is not darker than the female and both sexes look much like the female of *hirticulus*. Differs from *hirticulus* by being more fulvo-aeneous in coloration and by the membrane being dark fuscous; males easily distinguished by the genital claspers.

♂. Length 4.8 mm. *Head*: width across eyes .91 mm., vertex .35 mm., length .37 mm., height at base .57 mm.; yellowish brown, eyes dark brown; similar in structure to that of *hirticulus*. *Rostrum*, length 1.8 mm., reaching posterior margins of hind coxae, yellowish brown, apex darkened.

Antennae: segment I, length .57 mm., yellowish brown; II, 1.74 mm., yellowish brown, apex lightly infuscated; III, 1 mm., yellowish, slightly darkened with fuscous; IV, .68 mm., slightly darker than segment III.

Pronotum: length .91 mm., width at base 1.57 mm., width at anterior angles .74 mm., collar .63 mm.; similar to that of *hirticulus* but without fuscous on the sides. *Scutellum* rich brownish. *Sternum* yellowish brown, sides scarcely darker.

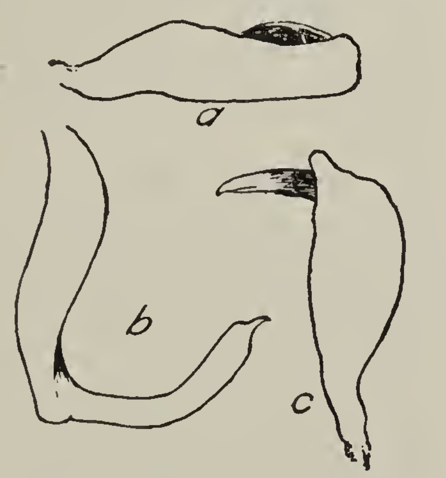

Fig. 183. LYGUS FAGI, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Hemelytra: greatest width 1.94 mm., rich brownish or fulvo-aeneous, the margin more yellowish, punctuation and pubescence about as in *hirticulus*; cuneus evenly shaded with yellowish brown, not darker at base. *Membrane* darkened with fuscous, darker within apices of cells, center of membrane, margin of apex, and a small spot each side near the tip of the cuneus.

Legs: yellowish brown, the femora frequently tinged with reddish, apices of tarsi fuscous.

Venter: brownish, tinged with reddish at the sides; genital claspers (fig. 183) distinctive of the species.

♀. Slightly larger and more robust than the male; very similar to the female of *hirticulus*, but usually distinguishable by the infuscated membrane and in general by the more fulvo-aeneous coloration.

This species breeds on beech (*Fagus grandifolia*) but is found only in favored surroundings, usually cool, shady situations. The nymphs hatch with the unfolding of the leaves and feed on the tender foliage. In 1916 the adults were maturing from June 20 to June 25; eggs were laid on the twigs of the host plant during July, and most of the adults were dead by August 1.

Described from 3 ♂ 5 ♀, July 23, Ithaca, New York, taken on beech by the writer.

Paratypes: 90 ♂ ♀ July 4–5, Four Mile, 17 ♂ ♀ June 25, Wyoming, ♂ ♀ June 26, ♀ July 5, ♂ July 25, Batavia, ♂ 2 ♀ June 23, Conesus Lake, ♂ June 27, Honeoye Falls, New York; all collected by the writer. 4 ♂ July 8, Norwich, ♂ July 14, Dummerston, Vermont; ♀ August 7, Chester, Massachusetts; all collected by C. W. Johnson and received from Mr. Parshley.

Lygus invitus Say

1831 *Capsus invitus* Say
Heterop. Hemip. N. Amer., p. 790. (Reprint.)
1916 *Lygus invitus* Knight
Can. ent. **48**:345.

Dark greenish with fuscous or blackish, sides of the body with a dark fuscous stripe extending the full length of the body and including the whole genital segment; scutellum with a pale median vitta on the apical half; disk of pronotum dark brownish or blackish, but never with two distinct rays as in *communis*; genital claspers distinctive of the species.

♂. Length 5 mm. *Head*: width across eyes .94 mm., vertex .32 mm., length .95 mm., height at base .51 mm.; dark greenish with brownish, eyes dark brownish to blackish; carina distinct, slightly arcuate, an impressed triangle just before, its apex extending as an impressed longitudinal line over the front; smooth shining, finely pubescent. *Rostrum*, length 1.57 mm., scarcely attaining the posterior margins of the hind coxae.

Antennae: segment I, length .55 mm., dark greenish with fuscous; II, 1.76 mm., dark greenish with fuscous, apical half becoming blackish; III, 1.14 mm., dark fuscous; IV, .65 mm., slightly darker than segment III; all the segments clothed with very fine pale pubescence.

Pronotum: length .9 mm., width at base 1.6 mm., width at anterior angles .74 mm., collar .57 mm.; dark greenish with fuscous, shining; lateral margins of disk paler, frequently bright green between and just before the calli; sides fuscous, xyphus bright green; calli nearly oval, smooth and shining, not at all prominent; punctures fine, closely placed and very shallow, more or less transversely confluent; fine yellowish pubescence. *Scutellum* dark brownish to fuscous, apical half of the median line pale, in some cases this pale vitta extending the full length of the scutellum; moderately convex, very finely transversely rugose, clothed with fine yellowish pubescence like hemelytra; mesoscutum only narrowly exposed. *Sternum* yellowish green beneath, sides and pleura infuscated, forming part of the fuscous stripe which extends the full length of the body; basalar plate bright green; scent-gland orifice infuscated.

Hemelytra: greatest width 2 mm.; dark fuscous with brownish, basal angle of the corium and basal half of the embolium paler; very finely punctate and minutely scabrous; clothed with very fine yellowish pubescence, thicker on the clavus; cuneus pale, transparent, in some cases tinged with greenish on the exterior margin. *Membrane* infuscated, paler bordering the cuneus, veins, basal half of cells, a large spot each side near the margin beyond the tip of the cuneus, and a smaller and less distinct spot beyond that halfway to the tip of the membrane.

Legs: coxae and bases of femora pale or greenish, posterior femora fuscous except at base, the middle pair in some cases darkened near the tips; tibiae pale greenish, the hind pair in some cases with a fuscous ring near the base or the whole tibia somewhat darkened; spines yellowish brown; apical tarsal segment blackish, claws brownish.

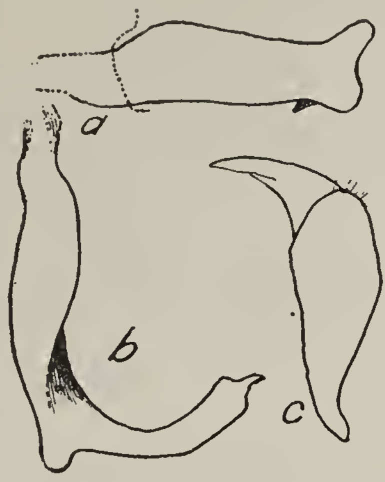

FIG. 184. LYGUS INVITUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Venter: pale beneath, sides dark fuscous, genital segment dark fuscous, shining, with a pale mark beneath at the base; spiracles appearing as pale dots; genital claspers (fig. 184) distinctive of the species.

♀. Length 5.1 mm., width 2.2 mm.; slightly more robust than the male; very similar in coloration to the male, but with the pale vitta on the scutellum more extended, and in general lighter-colored.

Redescribed from a large series of specimens collected by the writer from elm (*Ulmus americana*), June 20, Batavia, New York.

Records: 30 ♂ ♀ June 20, ♂ June 16, 2 ♂ June 21, 7 ♂ 3 ♀ June 25, ♂ June 28, ♂ 3 ♀ July 14, ♀ July 22, Batavia, 40 ♂ ♀ June 23, Conesus Lake, 4 ♂ 2 ♀ June 27, Honeoye Falls, ♂ June 21, Portage, ♂ June 9, ♀ June 16, ♂ ♀ July 26, Ithaca, New York; all collected by the writer. ♂ June 15, Danbury, ♂ ♀ June 16, Winnipauk, Connecticut; ♂ June 20, North Adams, Massachusetts; 5 ♂ ♀ June 28, Saint Johnsbury, ♂ July 8, Norwich, ♂ June 22, Burlington, Vermont; all collected by C. W. Johnson.

So far as the writer is able to determine, *invitus* breeds only on the elm (Ulmus), preferring always the young, thrifty plants with succulent shoots. The forty specimens recorded above from Conesus Lake, New York, were all taken on one small clump of second-growth elm shoots. The nymphs are pale greenish, hatching soon after the leaves come out in the spring from eggs that were inserted in the twigs the previous July. The adults all disappear by the first of August.

Lygus atritylus new species

Closely related to *invitus* and *fagi*, the darker forms much resembling a pale or yellowish form of *invitus*; easily distinguished by the blackish tylus and the genital claspers.

♂. Length 5.2 mm. *Head*: width across eyes 1.03 mm., vertex .43 mm., length .37 mm., height at base .6 mm.; yellowish brown marked with reddish, apical half of tylus blackish, eyes blackish. *Rostrum*, length 1.88 mm., just attaining posterior margins of hind coxae, yellowish brown, apex blackish.

Antennae: segment I, length .54 mm., yellowish brown or greenish; II, 1.82 mm., yellowish brown, tip in some cases slightly tinged with fuscous; III, 1 mm., yellowish green darkened with fuscous; IV, .63 mm., darker than segment III.

Pronotum: length .97 mm., width at base 1.71 mm., width at anterior angles .85 mm., collar .68 mm.; yellowish green to brownish, sides reddish, front margins of the calli in some cases marked with reddish. *Scutellum* same color as disk of pronotum. *Sternum* pale yellowish to greenish, sides marked with reddish as in *communis*.

Hemelytra: greatest width 2.2 mm.; greenish yellow to yellowish brown, punctuation and pubescence similar to that in *invitus*; embolium and exterior margin of corium paler, translucent; clavus may be infuscated along the suture, frequently the corium may be darkened with fuscous on the apical half; cuneus clear, in some cases tinged with yellowish. *Membrane* infuscated, a blackish inverted Y formed at the extreme base; a large pale spot at each side near the margin, also pale bordering the cuneus, veins, and bases of the cells.

Legs: greenish yellow, femora marked with reddish, usually forming an annulus near the apices of the posterior pair; tibial spines arising from fuscous spots as in *alni*; apices of tarsi fuscous, claws paler.

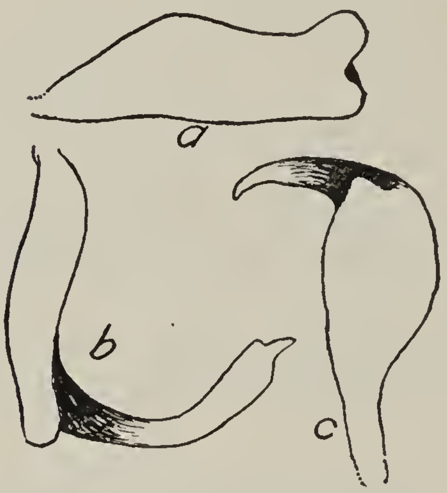

FIG. 185. LYGUS ATRITYLUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Venter: pale yellowish to greenish beneath, sides reddish as in *communis*; genital claspers (fig. 185) distinctive of the species.

♀. One mutilated specimen studied, in coloration very similar to the male; distinguished from all other species by the apical half of the tylus being blackish, in combination with the general yellowish brown coloration of the dorsum and the reddish stripe on the sides of the body.

Holotype: ♂ June 29, Stowe, Vermont, collected by G. P. Engelhardt.

Paratypes: ♂, Stowe, Vermont (G. P. Engelhardt). ♂, Franconia, New Hampshire (Mrs. A. T. Slosson). ♂ July 21, Happy Hollow, ♂ August 14, " Dutch Geo.," ♀ August 16, Home, Colorado; all received from C. P. Gillette.

This species appears to be rather scarce, and further information on its distribution and knowledge of its food plant will prove of interest.

Lygus confusus new species

Differs from *alni* in lacking the strong bronze colors, in having a fuscous spot at the tip of the corium, and in different membrane markings; the fuscous spots at the base of the tibial spines are much more distinct, and in addition there are small fuscous spots on the lower side of the posterior femora; the height of the lateral aspect of the sinistral forceps is greater in proportion to the length than in *alni* or any other species here considered.

♂. Length 5.3 mm. *Head*: width across eyes 1.08 mm., vertex .31 mm., length .46 mm., height at base .65 mm.; greenish to yellowish brown, eyes dark brown, thicker than in *belfragii* or *alni*; carina distinct, with an impressed triangle just before and joining with the slightly sulcate vertex. *Rostrum*, length 2.14 mm., attaining posterior margins of hind coxae, yellowish brown, apex blackish.

Antennae: segment I, length .66 mm., greenish yellow to brownish; II, 2.19 mm., same color as segment I; III, 1.2 mm., pale fuscous; IV, .77 mm., same color as segment III.

Pronotum: length 1 mm., width at base 1.74 mm., width at anterior angles .8 mm., collar .63 mm.; green with greenish yellow, slightly more yellowish brown on basal part of disk. *Scutellum* green or with yellowish brown at the sides and on the slightly exposed mesoscutum. *Sternum* greenish yellow.

Hemelytra: greatest width 2.05 mm.; clavus greenish yellow, more brownish near the scutellum and the suture; corium and embolium greenish yellow, inner apical angles of the corium with a small fuscous patch; cuneus yellowish green, translucent, pubescent. *Membrane* fuscous, darkest within apices of cells and a spot near apex of cuneus; veins, basal half of cells, between the large cells and bordering their apices, and bordering the cuneus, pale.

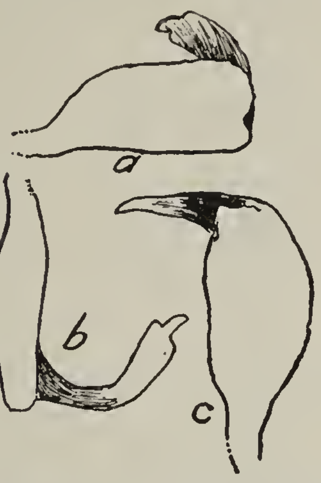

FIG. 186. LYGUS CONFUSUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Legs: greenish yellow, posterior femora with a few very small fuscous dots on the lower side, apices with two fuscous annuli apparent on the upper side; tibial spines yellowish brown, bases distinctly fuscous; tarsi yellowish brown, apices darker.

Venter: greenish yellow; genital claspers (fig. 186) distinctive of the species.

Described from a single male specimen, July 22, Machias, Maine, received from H. M. Parshley. One female specimen, July 16, Mount Washington, New Hampshire, agrees with the male in markings and doubtless belongs to this species.

Lygus alni new species

1909 *Lygus viridis* Reuter (not Fallén)
Bemerk. neark. Caps., p. 42.

Closely related to the European *Lygus viridis* Fallén, but differs in the male genital claspers, in having the scutellum noticeably darker, and in that the apical part of the second antennal segment is not infuscated; more slender than *viridis*, bright green, bronze on the clavus and on the basal half of the disk of the pronotum, with a more dilute bronze on the scutellum and on the inner half of the corium.

♂. Length 5.5–6 mm. *Head*: width across eyes 1 mm., vertex .33 mm., length .38 mm., height at base .58 mm.; yellowish brown tinged with green, eyes dark brown, lorae more strongly arcuate than in *belfragii*. *Rostrum*, length 1.88 mm., just reaching posterior margins of hind coxae, greenish to yellowish brown, apex fuscous.

Antennae: segment I, length .64 mm., yellowish; II, 2.02 mm., yellowish and not fuscous at tip as in *viridis*; III, 1.04 mm., slightly fuscous with pale at the very base; IV, .74 mm., slightly darker than segment III; all the segments with very fine pubescence.

Pronotum: length .86 mm., width at base 1.57 mm., width at anterior angles .63 mm., collar .57 mm.; bright green, bronze on the basal half of disk extending nearly to the calli but not darkening the green on the lateral margins; punctuation less noticeable than in *belfragii*; prosternal xyphus green like the sides of the pronotum. *Scutellum* dark green tinged with bronze. *Sternum* pale yellowish green, as are the sides of the thorax.

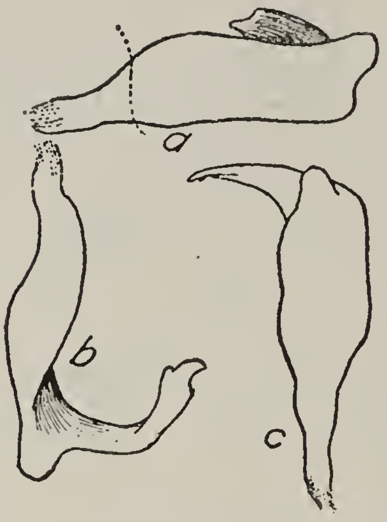

FIG. 187. LYGUS ALNI, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Hemelytra: greatest width 1.98 mm., pubescence rather short and fine, tinged with bronze; bright green, with the clavus strongly bronzed and the inner half of the corium lightly bronzed; cuneus bright green, in some cases the inner margin slightly bronzed. *Membrane* lightly infumed, with apical part of cells and a narrow transverse spot at apex of cuneus darker; veins scarcely paler than the membrane.

Legs: greenish, tibial spines fuscous at base, apices of tibiae and the tarsi yellowish brown, apices of the tarsi fuscous with the claws bronzed.

Venter: bright green to yellowish green; genital claspers (fig. 187) distinctive of the species.

♀. Not differing from the male in coloration but slightly more robust.

Holotype: ♂ July 27, McLean, New York (H. H. Knight).

Allotype: with the type.

Paratypes: 3 ♂ 13 ♀, topotypic. ♀ July 26, Ithaca, New York (H. H. Knight). ♂, Wolfville, Nova Scotia. ♂, Franconia, New Hampshire (Mrs. A. T. Slosson); lent for study by Mr. Heidemann, it being one of the two specimens recorded as *L. viridis* Fallén by Reuter (1909).

Specimens were taken only from alders (*Alnus incana*) growing in the cool and shady parts bordering the Round Bog at McLean, indicating that the species is of northern distribution. On that date, July 27, specimens were scarce; a few were undersized, showing them to be the last stragglers of the brood. The eggs are doubtless laid in the twigs of alder, where they spend the winter, hatching in the following spring with the unfolding of the leaves.

The writer has dissected out the male forceps of the specimen from Franconia, New Hampshire, and others of those mentioned above, and finds the structures showing a constant difference from the European *L. viridis* Fallén, specimens of which were determined by Reuter and sent to Mr. Heidemann (fig. 188).

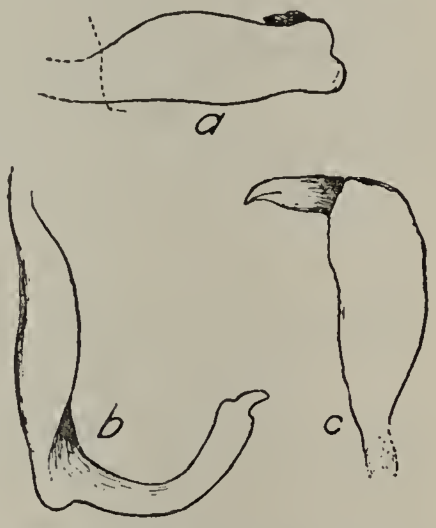

FIG. 188. LYGUS VIRIDIS FALLÉN, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Lygus geneseensis new species

Allied to *viburni*, having much the same color but differing in being slightly smaller, in the longer rostrum, and in the structure of the genital claspers.

♂. Length 5 mm. *Head*: width across eyes .97 mm., vertex .4 mm., length .4 mm., height at base .57 mm.; yellowish brown, tip of tylus darker. *Rostrum*, length 1.9 mm., reaching posterior margins of hind coxae, yellowish brown, apex dark brown.

Antennae: segment I, .68 mm., yellowish; II, 2.05 mm., yellowish, rarely if ever darkened at apex; III, 1.17 mm., yellowish, tinged with darker on the apical half; IV, .69 mm., yellowish tinged with fuscous.

Pronotum: length .97 mm., width at base 1.71 mm., width at anterior angles .77 mm., collar .6 mm.; similar in structure to that of *viburni*, but more of a fuscous brown in color. *Sternum* dark brown; pleura and orifice dark fuscous brown.

Hemelytra: greatest width 2.05 mm.; similar to those of *viburni* but usually with darker fuscous brown.

Legs: yellowish, darker on the femora and paler on the tibiae; posterior femora not annulated at the apices.

Venter: uniformly dark fuscous brown, genital segment more shining; genital claspers (fig. 189) distinctive of the species, recognized quickly by the form of the inner hook of the dextral clasper

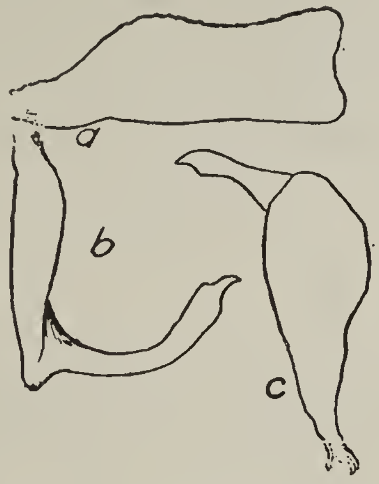

FIG. 189. LYGUS GENESEENSIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

♀. Length 4.9 mm., width 2.1 mm.; very similar to the male but more uniformly yellowish brown; distinguished from *viburni* by the uniformly yellowish color of the antennae, and by the length of the rostrum which reaches to the posterior margins of the hind coxae.

The species occurs on white oak (*Quercus alba*), in company with *quercalbae* but much less abundant. The life history is apparently similar to that of *omnivagus* and *quercalbae*.

Holotype: ♂ June 23, Conesus Lake, New York (H. H. Knight).

Allotype: with the type.

Paratypes: 26 ♂ ♀ June 23, Conesus Lake, 7 ♂ 2 ♀ June 21, 10 ♂ ♀ June 22, 4 ♂ 5 ♀ June 27, Portage, 3 ♀ June 25, Batavia, 3 ♂ July 26, Ithaca, New York; all collected by the writer. ♂ ♀ July 8, Yaphank, New York (Wm. T. Davis). 2 ♂ July 28, Pigeon Cove, Massachusetts (C. E. Olsen). ♂, Jeannette, Pennsylvania. ♂ June 16, Atherton, Missouri. ♂ June 14, Beltsville, Maryland; ♂ July 1, Bluemont, ♀ June 17, Glencarlyn, Virginia; all collected by W. L. McAtee.

Lygus viburni new species

Smaller than *omnivagus*, and more yellowish brown; closely related to *geneseensis*, but differs in the male claspers, in being more robust, in having a shorter rostrum, in the apical half of the second antennal segment being infuscated, and in having in general a richer yellowish brown color.

♂. Length 5.2 mm. *Head*: width across eyes 1.03 mm., vertex .38 mm., length .43 mm., height at base .63 mm.; yellowish brown, tip of the tylus darker; carina slightly arcuate, slightly impressed on the vertex just in front. *Rostrum*, length 1.54 mm., scarcely attaining posterior margins of intermediate coxae, much shorter than in *geneseensis*; yellowish brown, apex fuscous.

Antennae: segment I, length .57 mm., yellowish; II, 1.97 mm., yellowish on the base, apical half dark brownish to fuscous; III, 1.05 mm., fuscous brown, narrow pale ring at base; IV, .63 mm., fuscous brown.

Pronotum: length 1 mm., width at base 1.79 mm., width at anterior angles .83 mm., collar .6 mm.; uniformly rich yellowish brown, slightly paler at margins of disk and darker brown behind the coxal cleft; calli apparent as smooth ovals, a slightly impressed line defining the posterior margin; fine shallow punctures, fine yellowish pubescence. *Scutellum* yellowish brown, very finely transversely rugose, fine yellowish pubescence. *Sternum* yellowish beneath, fuscous brown on the sides; pleura fuscous brown; orifice pale.

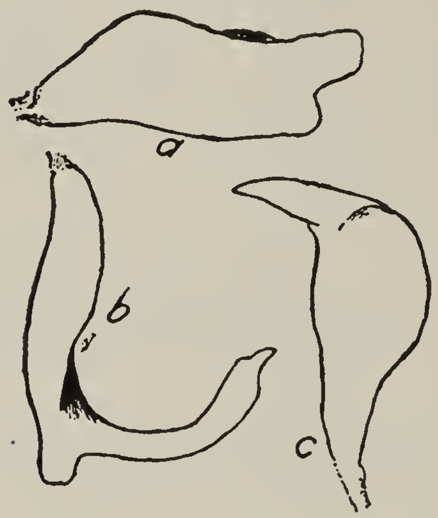

FIG. 190. LYGUS VIBURNI, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Hemelytra: greatest width 2.08 mm.; rich yellowish brown to dark brown; paler on the basal two-thirds of the embolium and adjacent margin of the corium; cuneus pale tinged with yellowish; fine shallow punctuation, more or less scabrous, fine yellowish pubescence. *Membrane* fuscous brown, paler bordering the apices of the cells and narrowly bordering the cuneus; a faint pale spot near the margin just beyond the apex of the cuneus.

Legs: pale yellowish; apical half of posterior femora brownish, twice annulated near the apices with dark brown, contrasted with pale; tibiae and spines yellowish; tips of tarsi dark brown, claws yellowish brown.

Venter: rich dark brown, yellowish beneath, genital segment entirely dark brown and shining; genital claspers (fig. 190) distinctive of the species, bearing a close resemblance to those of *parshleyi*.

♀. Length 5.3 mm., width 2.28 mm., width of head 1.03 mm., vertex .45 mm.; very similar to the male in coloration but usually not so dark; distinguished from *geneseensis* by the shortness of the rostrum, which scarcely attains the posterior margins of the intermediate coxae, and by the second antennal segment, which is darkened on the apical half.

The species breeds in large numbers on *Viburnum lentago*. It is often most numerous on the old plants. It is frequently found in company with *Lygidea rubecula* Uhl., but that species breeds particularly on young growth.

The nymphs hatch with the unfolding of the leaves and continue to feed on the tender foliage. In some cases the species may be classed as a pest on ornamental plantings, for it breeds in such numbers that all the leaves become spotted and curled, and many of them drop. The nymphs are greenish yellow in color, short, and more oval than those of most species of Lygus. The life history is very similar to that of *omnivagus* and *quercalbae*.

Holotype: ♂ July 9, Batavia, New York (H. H. Knight).

Allotype: with the type.

Paratypes: 11 ♂♀ June 14, 50 ♂♀ June 15, 56 ♂♀ June 16–25, 5 ♀ July 4, 4 ♂ ♀ July 9, 3 ♂ 8 ♀ July 10, 2 ♂ 2 ♀ July 27, 7 ♀ July 29–31, 9 ♀ August 2, ♀ August 6, Batavia, New York; 10 ♂♀ June 21, 17 ♂♀ June 27, Portage, New York; all collected by the writer. ♂ June 22, Bennington, Vermont. ♂ June 11, New Haven, Connecticut (B. H. Walden).

Lygus parshleyi new species

Closely related to *atrinotatus*, but differs materially in the male claspers, in not having the blackish rays on the pronotum clearly defined as spots, and in general by the more brownish coloration.

♂. Length 4.8 mm. *Head*: width across eyes 1 mm., vertex .4 mm., length .42 mm., height at base .57 mm.; yellowish brown to dark brownish, lorae, juga, and apical half of tylus darker; carina distinct, slightly arcuated, slightly depressed just in front of the vertex; front full, slightly depressed along the median line. *Rostrum*, length 1.54 mm., scarcely attaining posterior margins of hind coxae, yellowish brown, apex blackish.

Antennae: segment I, length .54 mm., yellowish brown to dark brown; II, 1.57 mm., yellowish brown, apex blackish; III, .94 mm., fuscous; IV, .68 mm., fuscous.

Pronotum: length .85 mm., width at base 1.63 mm., width at anterior angles .8 mm., collar .58 mm.; yellowish brown, with brownish black extending from the collar over the exterior half of the calli, widening toward posterior margin of disk, in some cases meeting at base and leaving a pale area only in center of disk and between the calli; sides fuscous or blackish, with yellowish at lateral margins of disk; punctuation and pubescence similar to that in other closely related forms. *Scutellum* yellowish to brownish, darker at the sides and on the mesoscutum; very finely transversely rugose with fine pale pubescence. *Sternum* yellowish beneath, fuscous at the sides; pleura fuscous; orifice pale.

Hemelytra: greatest width 2 mm.; yellowish brown, clavus and apical two-thirds of the corium and embolium dark brownish to blackish; cuneus pale translucent tinged with yellowish. *Membrane* infuscated, but not so dark as in *atrinotatus*; pale bordering the cuneus, along veins, in basal half of cells, and a faint spot near margin beyond apex of cuneus.

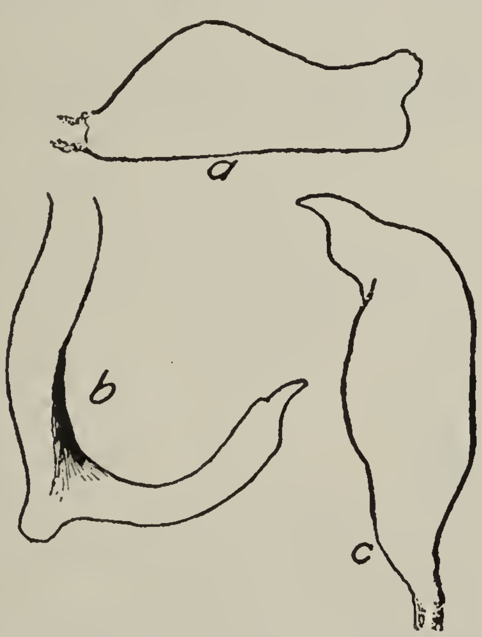

FIG. 191. LYGUS PARSHLEYI, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Legs: pale yellowish, posterior femora dark brownish or reddish brown on apical half, leaving two pale rings at apices; tibial spines brownish, apices of tarsi blackish, claws brownish.

Venter: pale beneath, sides with a dark brownish or fuscous stripe, genital segment dark brownish black, shining; genital claspers (fig. 191) distinctive of the species.

♀. Length 5 mm., width 2.1 mm.; the dark colors much reduced, otherwise similar to the male in coloration.

This species is named after H. M. Parshley, who was the first to send the writer specimens of this as well as certain other forms of Lygus.

Holotype: ♂ July 15, Glen House, New Hampshire.

Allotype: with the type.

Paratypes: ♂ ♀ June 26, Bretton Woods, New Hampshire (C. W. Johnson). 2 ♂ ♀ June 30, Bretton Woods, ♂ July 23, Glen House, New Hampshire; ♂ July 14, Eastport, Maine; all received from E. P. Van Duzee.

The food plant of this species is unknown to the writer.

Lygus parshleyi var. **shermani** new variety

Length 5.6 mm., width 2.5 mm. Larger than the typical *parshleyi* and more brownish than black; male claspers very similar to those of *parshleyi*, tho a slight difference may be noted in the dextral clasper. Second antennal segment entirely dark brownish or with the apical half blackish. Pronotum with the blackish rays much reduced, particularly in the females.

The structural differences are so small that it seems desirable to place this form as a variety of *parshleyi*, for the present at least.

Described from 5 ♂ 3 ♀, July 6, 1906, Highlands, North Carolina, received from R. W. Leiby; the specimens were collected by Franklin Sherman, after whom the variety is named.

Lygus inconspicuus new species

Pale greenish, with a transverse spot of brownish at the apex of the corium and dark brownish on the clavus bordering the scutellum; in general appearance resembling most the female of *tiliae* and both sexes of *clavigenitalis*, but differing greatly from those species in the form of the genital claspers.

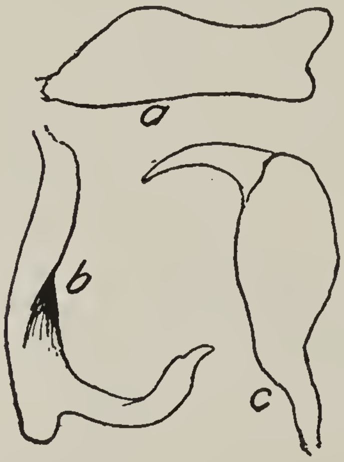

FIG. 192. LYGUS INCONSPICUUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

♂. Length 4.5 mm. *Head*: width across eyes .97 mm., vertex .37 mm., length .32 mm., height at base .56 mm.; yellowish green; eyes dark brown, paler at margins; carina distinct, an impressed line curving from the corner of each eye onto the vertex; head shorter and more vertical than is usual in the genus. *Rostrum*, length 1.54 mm., attaining posterior margins of hind coxae, yellowish green, apex blackish.

Antennae: segment I, length .48 mm., greenish; II, 1.65 mm., yellowish green, apex tinged with fuscous; III, .77 mm., fuscous; IV, .48 mm., fuscous.

Pronotum: length 1 mm., width at base 1.7 mm., width at anterior angles .77 mm., collar .61 mm.; greenish or yellowish green, disk tinged with brownish; very minutely and shallowly punctate, very fine pale pubescence; calli scarcely distinguishable, indicated only by a slight change in color. *Scutellum* pale yellowish, more yellowish at margins; very minutely rugose, very fine pale yellowish pubescence. *Sternum* pale yellowish green beneath, sides and pleura green; orifice pale.

Hemelytra: greatest width 2.08 mm.; clavus dark brownish, darker on the half bordering the scutellum; corium pale greenish, apex transversely darkened with dark brownish or fuscous; embolium in some cases slightly darkened bordering the fuscous spot on the corium; very minutely scabrous, fine yellowish pubescence; cuneus pale with greenish, in some cases strongly green. *Membrane* pale, apices of cells, a small spot at tip of cuneus, and one beyond near the margin, pale fuscous.

Legs: green, paler at base of femora; tibiae darker green, spines brownish; apices of tarsi and extreme tips of tibiae fuscous, claws yellowish.

Venter: green, slightly paler beneath; genital claspers tinged with brownish, in structure distinctive of the species (fig. 192).

♀. Length 4.8 mm., width 2.25 mm.; very similar to the male in size and coloration. Similar in size and general appearance to females of *clavigenitalis* and *tiliae*; distinguished from *tiliae* by the pale scutellum, and from *clavigenitalis* by the more greenish color and the paler scutellum.

Described from specimens taken on *Carpinus caroliniana*, the trees also being covered by wild grapevines. The writer was unable to definitely locate the food plant, tho apparently the species feeds on one of the two plants named. Continued sweeping of the supposed food plants failed to produce any great number of specimens, thus giving evidence of the rarity of the species in western New York. The number of specimens taken by W. L. McAtee in the vicinity of the District of Columbia indicates that the species may be more abundant in that region.

Holotype: ♂ July 9, Batavia, New York (H. H. Knight).

Allotype: with the type.

Paratypes: 3 ♂ June 24, ♀ June 25, ♂ July 9, ♀ July 10, Batavia, 2 ♂ Honeoye Falls, ♀ June 23, Conesus Lake, New York; all collected by the writer. 5 ♂ 3 ♀ July 1, Bluemont, ♂ May 31, Four Mile Run, ♀ Glencarlyn, Virginia; 4 ♀ June 14, Beltsville, Maryland; all collected by W. L. McAtee.

Two female specimens that apparently belong here: ♀ June 23, New Haven, Connecticut (B. H. Walden); ♀ June, Clayton, Georgia, altitude 2000–3700 feet (Wm. T. Davis).

Lygus tiliae new species

Rather small, scarcely as large as *invitus*; greenish yellow with the base of the pronotum darker, the scutellum, the clavus, and the corium dark fuscous to blackish (♂), or with the dark color greatly reduced forming fuscous triangles at the apex of the corium (♀); female very much resembles forms of *inconspicuus* and *clavigenitalis*.

♂. Length 4.6 mm. *Head*: width across eyes .94 mm., vertex .34 mm., length .4 mm., height at base .6 mm.; greenish with yellow, eyes dark brown, front strongly projecting, rounded, shining; carina nearly straight, slightly impressed before and joining with a narrow longitudinal sulcus on the median line of the vertex. *Rostrum*, length 1.6 mm., yellowish brown, apex blackish.

Antennae: segment I, length .54 mm., greenish yellow; II, 1.71 mm., yellowish; III, .94 mm., fuscous, yellowish at base; IV, .63 mm., fuscous; all the segments finely pubescent.

Pronotum: length .88 mm., width at base 1.63 mm., width at anterior angles .77 mm., collar .6 mm.; anterior part, including the calli, yellowish, sides and lateral margins of disk strongly greenish, basal half of disk fuscous or dark greenish to blackish; calli, punctuation, and pubescence as in *belfragii*. *Scutellum* dark fuscous, pale pubescent, finely transversely rugose; mesoscutum dark fuscous, in some cases with yellowish. *Sternum* greenish yellow to yellowish, sides of thorax pale yellowish.

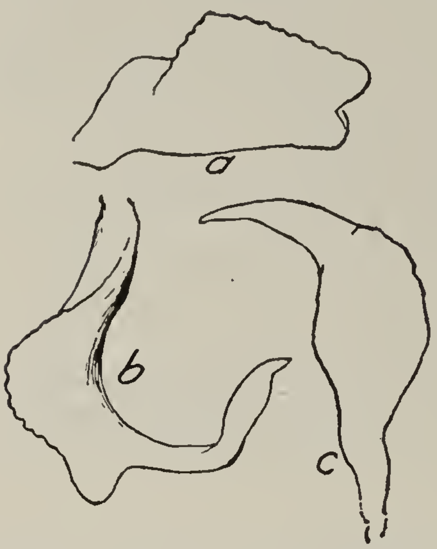

FIG. 193. LYGUS TILIAE, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Hemelytra: greatest width 1.74 mm.; clavus and inner half of corium dark fuscous to blackish, exterior basal half of corium pale greenish; embolium greenish, in some cases tinged with fuscous near the tip; cuneus green or faded to yellowish; fine pale pubescence, finely and shallowly punctured with a roughened irregular rugose effect. *Membrane* evenly fuscous, veins paler at apices of cells; in many specimens the basal half of the cells, and surrounding a small spot near the apex of the cuneus, paler.

Legs: greenish yellow; tibiae more greenish, spines brownish; apical segments of tarsi brownish to fuscous, claws brown.

Venter: greenish with yellowish, sides and genital segment becoming fuscous; genital claspers (fig. 193) distinctive of the species.

♀. Length 5 mm., width 2 mm.; lighter-colored than the male and usually slightly larger; pronotum entirely yellowish, scutellum and clavus only slightly darkened, apex of the corium with a triangular dark patch, much resembling *belfragii* in this respect; similar in size and general appearance to females of *inconspicuus* and *clavigenitalis*; distinguished from *inconspicuus* by having a more conical shape to the front of the head, and in the darker-colored scutellum; *clavigenitalis* differs in having more brownish and in the paler scutellum.

The species breeds abundantly on linden (*Tilia americana*) and appears to be limited at least to this genus of plants. The nymphs hatch with the unfolding of the leaves and usually mature from June 15 to June 25. The females lay their eggs in the young twigs of the linden during July, and by the end of the month most of them have died. The insects are frequently attracted to sumac (*Rhus glabra*) for feeding on the flowers, and in this way thirty-seven specimens were taken on July 10.

Described from 131 specimens taken on one linden tree at Portage, New York, on June 27, 1915.

Holotype: ♂ June 27, Portage, New York (H. H. Knight).

Allotype: with the type.

Paratypes: 129 ♂ ♀, topotypic. From near Batavia, New York, 2 ♂ June 10, 29 ♂ ♀ June 14–16, 38 ♂ ♀ June 20–25, 9 ♂ ♀ July 5–9, 7 ♀ 30 ♂ July 10 (from *Rhus glabra* flowers), ♀ July 21, ♂ July 25, 3 ♀ August 1, ♀ August 13; 3 ♂ 4 ♀ June 16, Wyoming, ♂ June 15, Ithaca, 3 ♂ 9 ♀ July 16, Conesus Lake, ♂ June 27, Honeoye Falls, 2 ♂ 2 ♀ July 4, Four Mile, New York; all collected by the writer. 3 ♂

June 25, Spring Brook, New York; 2 ♂ 2 ♀ June 29, Ottawa, Ontario; all received from E. P. Van Duzee. ♂ June 27, Poquonock, Connecticut (H. L. Viereck). ♂ July 13, Springfield, Massachusetts (C. W. Johnson). ♀ July, Middlebury, Vermont.

Lygus caryae new species

Dark brownish to black, the cuneus pale, thus superficially resembling *Neoborus geminus* Say, while the paler brown forms suggest *Lygus omnivagus*; the yellowish pubescence on the dark color gives a dull wax-like shine to the insect.

♂. Length 5.4 mm. (variation 4.8–5.7 mm.). *Head*: width across eyes 1.05 mm., vertex .4 mm., length .43 mm., height at base .6 mm.; brownish black to nearly black, eyes dark brown; vertex with a longitudinal impressed line similar to that in *invitus*. *Rostrum*, length 1.91 mm., scarcely attaining posterior margins of hind coxae, pale to yellowish brown, apex fuscous.

Antennae: segment I, length .65 mm., greenish yellow tinged with fuscous; II, 2.05 mm., yellowish brown darkened with fuscous, in some cases nearly black; III, 1.02 mm., pale tinged with fuscous; IV, .65 mm., slightly darker than segment III; fine silvery pubescence covering all the segments except the first, which has slightly heavier and darker pubescence.

Pronotum: length .97 mm., width at base 1.79 mm., width at anterior angles .83 mm., collar .65 mm.; black, in some cases the calli with dark brown; a spot of greenish brown at dorsal extremity of coxal cleft, prosternal xyphus greenish yellow; disk, especially on basal half, transversely rugulose. *Scutellum* black, transversely rugulose, in some cases the apex brownish. *Sternum* brownish black, the median ventral part greenish yellow; pleura brownish black; orifice black.

Hemelytra: greatest width 2.1 mm.; yellowish pubescence rather prominent on the dark dorsum; clavus and corium black, in some cases slightly brownish black; cuneus clear with the apex fuscous, frequently clouded along the basal margin. *Membrane* and veins fuscous, frequently nearly black; brachium at apex of larger cell usually pale.

Legs: greenish yellow, apical segments of tarsi and apical half of posterior femora, excepting the very tips, fuscous; middle femora annulated near the apices with two narrow fuscous rings, showing darker on the ventral side.

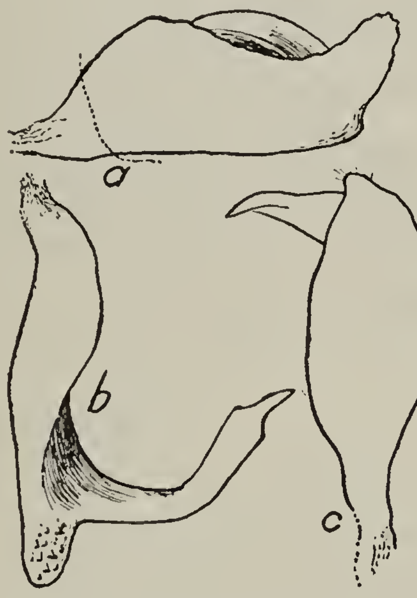

FIG. 194. LYGUS CARYAE, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Venter: black or brownish black, small yellowish spots inclosing the spiracles; rather long pale yellowish pubescence covering the genital segment and especially along the posterior margins of all the segments; genital claspers (fig. 194) distinctive of the species.

♀. Length 5.5 mm. (variation 5–6.3 mm.), width across eyes 1.03 mm., vertex .44 mm.; more robust than the male; frequently with brownish yellow between the calli and extending back over the disk.

Holotype: ♂ June 19, 1915, Batavia, New York (H. H. Knight).
Allotype: June 15, 1915, Batavia (H. H. Knight).

Paratypes: 32 ♂ ♀ June 5, 2 ♂ ♀ June 15, 5 ♂ 3 ♀ June 16, ♂ ♀ June 17, 3 ♂ 2 ♀ June 18–19, 3 ♂ June 24, ♂ ♀ June 25, ♂ ♀ July 1, 4 ♂ 4 ♀ July 14, Batavia, 2 ♂ 5 ♀ June 21, ♂ 2 ♀ June 27, Portage, 35 ♂ ♀ June 23, Conesus Lake, ♂ June 27, Honeoye Falls, 26 ♂ ♀ June 7, ♂ ♀ June 13, 5 ♂ 8 ♀ June 14, Ithaca, New York; all collected by the writer. 2 ♂ June 20, Honeoye Falls, New York (M. D. Leonard). ♂ 2 ♀ June 12, Hamburg, New York (E. P. Van Duzee). ♂ June 17, 3 ♂ 2 ♀ June 11, Boston, Massachusetts (collected at light, H. M. Parshley). ♂ ♀ June 5, Portland, ♂ June 21, ♂ ♀ June 24, New Haven, ♂ June 27, Yalesville, Connecticut (B. H. Walden). ♂ ♀ June 22, Bennington, Vermont (C. W. Johnson). 5 ♂ ♀ June 23, Beaver Dam, Wisconsin (W. E. Snyder). ♂ May 20, Agricultural College, Mississippi (L. O. Smith).

The species breeds on the various kinds of hickory (Carya) in New York. At Conesus Lake, New York, it was found on young black walnut trees (*Juglans nigra*). The adults are frequently attracted to sumac (*Rhus typhina*) for feeding on the flowers. In the Southern States the species breeds also on pecan.

The life history is very similar to that of *invitus* and that of *communis*, the nymphs feeding on the tender foliage of hickory. On June 5, 1914, near Batavia, New York, the writer found freshly emerged adults and fifth-stage nymphs in abundance on *Carya alba*. At other times the species was taken on *Carya ovata*.

Lygus caryae var. **subfuscus** new variety

A yellowish brown color form of the preceding species, to which it seems advisable to give a varietal name since in general appearance it differs so greatly from the typical species; very much resembling *omnivagus* in coloration.

♂. Genitalia showing no noticeable difference from that of *caryae*; second antennal segment brownish with fuscous, the basal one-third, and frequently one-half, yellowish brown as the first segment; yellowish brown, pronotum with two black spots, one behind each eye and frequently extending back over the calli thus forming two black rays; scutellum pale yellowish, frequently fuscous at base, in darker specimens a fuscous median line extending from base toward apex. Hemelytra in color very much resembling those of *omnivagus*, but the two black rays on the pronotum and the dark color of the scutellum appearing along the median line will distinguish it at once from that species. Ventral parts greenish yellow, with fuscous appearing on sides of thorax and in some cases rather dark on sides of venter; posterior femora with two narrow fuscous bands near the apices, darkest on the ventral side, middle and front femora in some cases showing these marks on the lower side.

A large series of this variety was taken by the writer on a hickory tree near Batavia, New York, on June 18, 1915, and only one specimen was dark enough to be classed as the typical *caryae*.

Holotype: ♂ June 18, 1915, Batavia, New York (H. H. Knight).
Allotype: with the type.
Paratypes: 81 ♂ ♀ June 18, ♀ June 26, 3 ♂ ♀ July 11, Batavia, ♂ June 25, Wyoming, 3 ♂ June 27, Portage, 6 ♀ June 23, Conesus Lake, New York; all collected by the writer. ♀ June 25, Spring Brook, New York (E. P. Van Duzee). ♀ June 5, Portland, Connecticut (B. H. Walden). ♂ June 7, South Meriden, Connecticut (H. Johnson). ♀ June 11, Boston, Massachusetts (H. M. Parshley). ♂ 2 ♀ April 4, Ocean Springs, Mississippi (on pecan, R. W. Harned). 2 ♀ April 30, Pascagoula, Mississippi (L. Brown).

Lygus atrinotatus new species

Resembles *canadensis* var. *binotatus* and certain color forms of *parshleyi*, but differs greatly in the genital claspers; yellowish brown, the second antennal segment and two conspicuous spots on the pronotum black; clavus, apical half of the corium, and narrow lateral margins of the scutellum, blackish; a blackish stripe on the sides extending the full length of the body.

♂. Length 4.7 mm. *Head*: width across eyes 1 mm., vertex .35 mm., length .37 mm., height at base .57 mm.; yellowish brown, tip of tylus slightly darkened, eyes dark brown; carina prominent, strongly arcuate. *Rostrum*, length 1.6 mm., reaching only to posterior margins of intermediate coxae, yellowish brown, apex blackish.

Antennae: segment I, length .6 mm., yellowish brown; II, 1.85 mm., black, with a very narrow yellowish ring at base; III, 1.03 mm., blackish, slightly paler at base; IV, .7 mm., blackish.

Pronotum: length .97 mm., width at base 1.71 mm., width at anterior angles .8 mm., collar .6 mm.; yellowish brown with two prominent black spots on the disk, one behind each callus and forming nearly square spots, each as wide as the callus and extending back two-thirds of the distance to basal margin; blackish at sides behind coxal cleft; finely and shallowly punctate, fine yellowish pubescence. *Scutellum* pale yellowish, sides bordering the clavus narrowly black; very finely transversely rugose, pale pubescent. *Sternum* pale yellowish beneath, blackish at the sides; pleura blackish; orifice of scent glands pale.

Hemelytra: greatest width 2.08 mm.; clavus black, a narrow yellowish line extending the full length, in some cases widened at the base; corium yellowish brown, the apical one-half blackish, in some cases brownish bordering the entire length of the clavus; embolium yellowish, apical one-third blackish, very minutely scabrous, yellowish pubescent; cuneus pale translucent, in some cases tinged with yellowish. *Membrane* dark fuscous, a spot near the margin beyond tip of cuneus, bordering the cuneus and veins, and basal half of cells, pale.

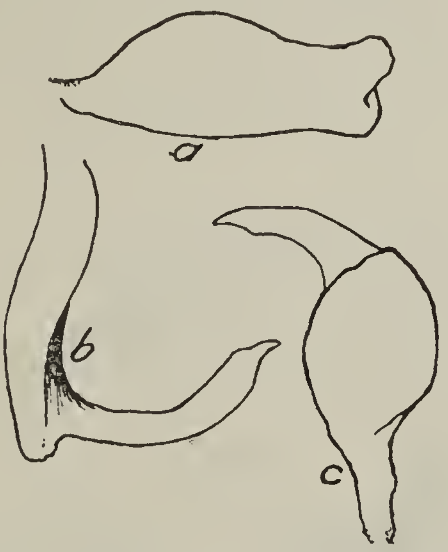

Fig. 195. Lygus atrinotatus, male genital claspers

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Legs: pale yellowish green; apical half of the posterior femora blackish except extreme tips; intermediate femora with two fuscous marks on the underside near the apices; tibial spines yellowish brown, apices of tarsi fuscous, claws brownish.

Venter: pale yellowish brown beneath and along the latero-dorsal margin, a narrow blackish line on the sides and extending to include most of the genital segment; genital claspers (fig. 195) distinctive of the species.

♀. Length 5.5 mm., width 2.3 mm.; slightly larger and more robust than the male but very similar in coloration.

Holotype: ♂ July 5, Pittsburg, Pennsylvania (S. L. Mason).

Allotype: with the type.

Paratypes: ♂ June 15, Black Mountains, North Carolina (Beutenmuller). ♂ July 21, Washington, D. C. (Nathan Banks).

Lygus vitticollis Reuter

1876 *Lygus vitticollis* Reuter
Caps. Amer. bor., p. 71.
1886 *Lygus monachus* Uhler
Can. ent. **18**:208.

Large and elongate, easily distinguished by its large size and black markings; pale yellowish; two rays on the pronotum, clavus, apical half of the posterior femora, apices of the corium and embolium, black; rostrum reaching only upon the intermediate coxae.

♂. Length 5.8–6 mm. *Head*: width across eyes 1.03 mm., vertex .31 mm., length .45 mm., height at base .63 mm.; yellowish to yellowish brown, eyes dark reddish brown; carina nearly straight, a small triangle impressed on the vertex just in front. *Rostrum*, length 1.63 mm., reaching only to middle of intermediate coxae, yellowish brown, apex darkened.

Antennae: segment I, length .77 mm., yellowish; II, 2.48 mm., yellowish, apex fuscous; III, 1.48 mm., fuscous, base more yellowish; IV, .56 mm., blackish; all the segments with fine pale pubescence.

Pronotum: length 1.14 mm., width at base 1.94 mm., width at anterior angles .74 mm., collar .65 mm.; pale yellowish brown with two black stripes on the disk: black stripe including exterior half of callus and extending back to base, where the blackish color is diffused along the margin; calli apparent as slightly raised shining ovals; transversely rugose on the disk, the shallow punctures indistinct and confluent; fine yellowish pubescence. *Scutellum* pale yellowish with fine pale pubescence. *Sternum* yellowish, in some cases fuscous on the sides and on the pleura.

Hemelytra: greatest width 2.48 mm.; pale yellowish tinged with brown; clavus black, in pale specimens the exterior half may be yellowish; corium yellowish with blackish across the tip, in dark specimens the black extending to form a wedge-shaped spot, partly on the embolium and on the exterior apical angle of the corium; cuneus pale tinged with yellowish; finely punctate, more or less scabrous, yellowish pubescence. *Membrane* fuscous, pale bordering the cuneus, on veins at apices of cells, and in a spot each side joining the margin just beyond the apex of the cuneus.

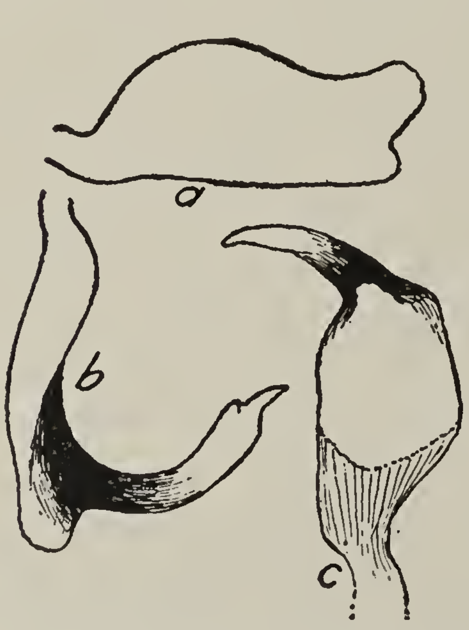

Fig. 196. LYGUS VITTICOLLIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Legs: pale yellowish brown, apical half of posterior femora brownish black to black; tibiae frequently greenish, spines pale yellowish; tips of tarsi pale fuscous, claws brownish.

Venter: pale to yellowish brown, a faint fuscous stripe on the sides, genital segment dark brownish to blackish; genital claspers (fig. 196) distinctive of the species.

♀. More robust than the male, but not differing from the male in coloration.

This species breeds on maple, particularly *Acer saccharum* and *A. rubrum*. The nymphs are found most abundantly on second-growth wood. At Four Mile, New York, where there are extensive tracts of second-growth maple, the writer was able to catch innumerable specimens. The species has also been found breeding abundantly in certain nursery plantings, the trees in which would be distributed for ornamental purposes. The species spends the winter in the egg stage on the host plant, and it is thus seen how easily it may become widely distributed in this country, and in foreign countries should the trees be sent abroad.

The nymphs hatch with the unfolding of the leaves and feed on the tender foliage, the life history being similar to that of other species such as *invitus* and *communis*. The nymphs differ from those of all other species of Lygus by their uniform pale whitish color, this making them hard to be seen when hidden on the underside of a maple leaf. The adult on emerging is also entirely pale, and gets the black markings only after a few hours drying.

In the original description Reuter gives Texas as the type locality for *vitticollis*. The writer is inclined to believe, after having studied the food plants and the distribution of the species, that the type specimen came from New York, as did certain other species furnished by Mr. Belfrage. It is quite possible that the collector got the specimens or labels mixed in the process of mounting, and this would account for the Texas record.

The writer has seen the specimen which was sent over by Mr. Heidemann, and which Reuter (1909) compared with the type, pronouncing it to be identical with *vitticollis*.

Records: 250 ♂♀ July 4–5, Four Mile, 118 ♂♀ June 20, Batavia, New York, all taken from one small clump of second-growth sugar maple; ♂ June 16, ♀ July 22, Batavia, 24 ♂♀ June 27, Honeoye Falls, New York (H. H. Knight). 3♂ 3 ♀ July 4–7, Bayshore, Long Island (C. E. Olsen). ♀, Marquette, Michigan (Wm. T. Davis).

Lygus neglectus new species

Bright green or yellowish green, robust, shorter and broader than *pabulinus*; easily distinguished from that species by the presence of a distinct carina, the genital claspers also distinct; head, calli, and ventral side of the body, yellow, a small fuscous cloud at base of membrane and inner angles of cuneus.

♂. Length 5.2 mm. *Head*: width across eyes 1.08 mm., vertex .4 mm., length .43 mm., height at base .68 mm.; strongly yellow, smooth shining, carina normal, eyes dark brown. *Rostrum*, length 1.79 mm., scarcely reaching posterior margins of hind coxae, green to yellowish, apex darkened.

Antennae: segment I, length .6 mm., yellowish with some greenish, bright green in female; II, 1.82 mm., greenish yellow becoming brownish at tip, slender, tapering larger toward the apex; III, .94 mm., dark brownish; IV, .45 mm., brownish to fuscous.

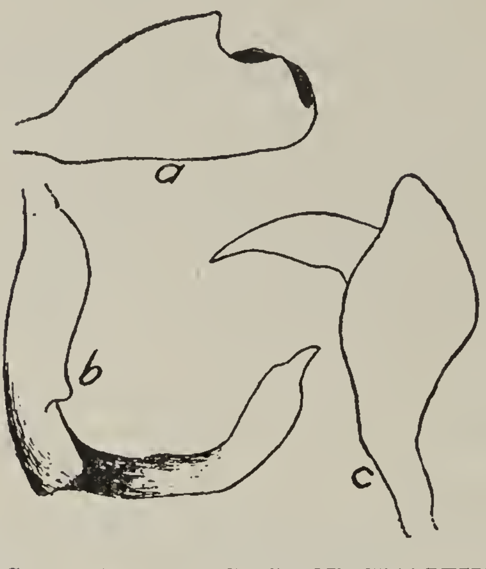

FIG. 197. LYGUS NEGLECTUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Pronotum: length .57 mm., width at base 2 mm., width at anterior angles .85 mm., collar .68 mm.; bright greenish to yellowish; finely and shallowly punctured as in *communis*; fine pale pubescence.

Hemelytra: greatest width 2.3 mm.; green or yellowish green, fine pale pubescence; shallowly punctured and slightly wrinkled. *Membrane* pale, junction of inner angle of cuneus and corium, and to some extent within base of large cell, clouded with fuscous. *Scutellum* yellowish green, fine pubescent, transversely rugulose. *Sternum* greenish yellow.

Legs: greenish yellow; tibiae strongly greenish, posterior pair irregularly curved, spines prominent, yellowish brown; tarsi slightly darkened at the apices.

Venter: yellowish, sides more greenish; genital claspers (fig. 197) very distinctive of the species.

♀. What appears to be the female of this species agrees with the male in the shape and the yellow color of the head, and in the fuscous marking at the inner basal angles of the cuneus and the membrane.

Length 5.6 mm., greatest width 2.4 mm.; first antennal segment, embolium, exterior half of the cuneus, tibiae, and apical half of the femora, noticeably bright green. The male described above has doubtless faded considerably.

Holotype: ♂ July 26, Manomet, Massachusetts.

Allotype: July 25, Tisbury, Massachusetts (H. M. Parshley).

Paratypes: 14 ♂ ♀ June 9, Auburn, Alabama, taken by the writer on *Carpinus caroliniana*.

Lygus communis Knight

1913 *Lygus invitus* Parrott and Hodgkiss (not Say)
New York Agr. Exp. Sta., Bul. 368.
1915 *Lygus invitus* Knight (not Say)
Journ. econ. ent. 8:296.
1916 *Lygus communis* Knight
Can. ent. 48:346.

Easily distinguished from *invitus* by the two black rays on the disk of the pronotum, by the reddish color in the lateral stripe on the body, and by the larger size; differs structurally in not having the impressed longitudinal line on the vertex and in the form of the genital claspers.

♂. Length 5.5 mm. *Head*: width across eyes 1.03 mm., vertex .43 mm., length .4 mm., height at base .63 mm.; yellowish brown or greenish marked with reddish; basal half of tylus, arched parts of juga, lorae, and bucculae, marked with reddish, also the front frequently marked with red in the form of transverse lines; apical half of the tylus dark brownish to fuscous; vertex full, without an impressed longitudinal line as in *invitus* but having a slight triangular flattened space just before the carina; eyes dark brownish, in some cases faded to pale on the margins. *Rostrum*, length

1.85 mm., reaching to near posterior margins of hind coxae, yellowish to brownish, apex blackish.

Antennae: segment I, length .57 mm., greenish frequently darkened with brownish; II, 2 mm., dark brownish to fuscous, in some cases basal half paler; III, 1.2 mm., dark brownish; IV, 1.08 mm., same color as segment III; all the segments with very fine pale yellowish pubescence.

Pronotum: length .94 mm., width at base 1.77 mm., width at anterior angles .91 mm., collar .68 mm.; greenish, darkened with brownish on the basal half, two blackish rays on the disk, one behind each callus and in the darkest specimens extending across the calli, widening behind, and nearly reaching the basal margin; coxal cleft marked with reddish, sides posterior to this much darkened; disk shining, very finely and closely punctured, the punctures more or less transversely confluent especially on the basal half. *Scutellum* greenish darkened with brownish, transversely rugose; specimens maturing on Ilex and on Cornus frequently with a longitudinal median fuscous line. *Sternum* pale beneath, with the sides reddish as are also the pleural sclerites.

Hemelytra: greatest width 2.3 mm., closely and minutely punctured, slightly scabrous, with fine yellowish pubescence; dark brownish to fuscous, darker on apical half of corium and across tip of embolium; embolium except tip, base, and narrow lateral margin of corium, pale greenish; cuneus clear tinged with yellow, the extreme tip in some cases slightly darkened; membrane darkened with fuscous; veins, narrow margin at apices of cells and bordering cuneus, a spot along margin beyond apex of cuneus and extending inward to cells, pale, thus isolating a fuscous spot along margin close to apex of cuneus.

Legs: coxae pale, usually with a spot of reddish at the base, femora greenish to yellowish, the posterior femora and often the intermediate pair twice annulated near the apices with reddish, frequently the whole apical half somewhat reddish; tibiae greenish, in some cases slightly darkened toward the tips, spines pale brownish; tarsi yellowish to brownish, darker at the apices.

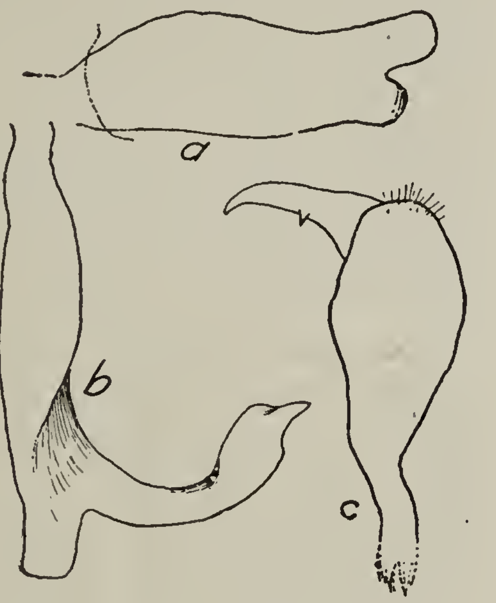

FIG. 198. LYGUS COMMUNIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Venter: pale greenish beneath, a broad lateral band and the genital segment dark reddish with brownish; genital claspers (fig. 198) distinctive of the species. The spine shown on the dextral clasper is not present in *invitus*, and is usually visible in pinned specimens without dissection.

♀. Slightly broader and more robust than the male; not differing materially in coloration, tho usually paler than the male.

This is the species commonly known as the false tarnished plant bug, and is a destructive species to the cultivated pear. An account of the life history and descriptions of the stages are given by Parrott and Hodgkiss (1913). The species is found most commonly breeding on Cornus, particularly *C. stolonifera* and *C. paniculata*. The writer has reared specimens from *Cornus alternifolia* and *Ilex verticillata*, and has taken freshly matured specimens on the prickly ash (*Zanthoxylum americanum*).

The nymphs hatch with the unfolding of the leaves and feed on the tender foliage. In the case of pear the nymphs attack the young fruit as soon as it forms, and continue to feed on this in preference to the leaves. All pears thus punctured become knotty and scarred to such an extent that the fruit is unsalable. The nymphs are pale green in color, closely matching the color of the young fruit, which makes it difficult for the observer to see them. The nymphs mature in about twenty-four days, or usually by the middle of June. The adults likewise prefer to feed on the pears, and contribute further to the destruction of the fruit. In one case the writer observed that the adult bugs were active agents in distributing pear blight (*Bacillus amylovorus*) over the trees, the blight developing about feeding punctures made by the bugs. One row of trees bordering a fence, on which the bugs were most numerous, had every limb blighted, which contrasted greatly with the trees on which no bugs were present.

Oviposition occurs during the last week in June and up to the middle of July, some individuals probably laying after that date. The eggs are inserted under the bark of the new growth (Knight, 1915); in one case observed six eggs were deposited in a mass. Most of the males die by the middle of July, but many females live until the end of the month. Two females kept in a cage on a pear tree lived until August 6 but were found dead on August 8. There is only one brood, the winter being passed in the egg stage and the nymphs appearing again in the spring with the unfolding of the leaves.

The species was described from specimens collected from pear by the writer on July 4, 1914, near Batavia, New York.

Paratype records: 67 ♂ ♀ taken on pear, June 16 to August 8, Batavia, New York; from *Cornus stolonifera*, 35 ♂ ♀ June 14 to August 6, Batavia; from *Cornus paniculata*, 5 ♂ ♀ June 21, 10 ♂ ♀ August 1, 6 ♀ August 10, Batavia; from *Cornus alternifolia*, 16 ♂ ♀ June 25–29, Batavia, 3 ♂ ♀ June 25, Wyoming, 8 ♂ ♀ June 21, Portage, ♂ 2 ♀ July 27, McLean, New York; from *Ilex verticillata*, 15 ♂ ♀ June 21, Batavia. Miscellaneous specimens: 16 ♂ ♀ June 25–29, from near Batavia, 7 ♂ ♀ June 27, Portage, 5 ♂ ♀ July 5, Four Mile, 2 ♂ June 13, 3 ♀ July 24, Ithaca, 4 ♂ 2 ♀ June 23, Conesus Lake, New York; all the above collected by the writer. Specimens from other collectors: ♀ June 25, Spring Brook, ♂ July 2, Hamburg, ♂ ♀ July 20, Salamanca, New York; ♂ June 30, Bretton Woods, New Hampshire; all collected by E. P. Van Duzee. 2 ♂ June 22, Bennington, Vermont; ♂ ♀ July 15, Eastport, ♀ July 12, Capens, Maine; 2 ♂ July 15–24, Glen House, New Hampshire; all collected by C. W. Johnson. A male specimen from Fort Collins, Colorado, August 1, which has an unusual amount of reddish on the underside of the body. Later records: ♀ June 17, Middletown, Connecticut (C. W. Johnson). ♂ July 13, Swampscott, Massachusetts (H. M. Parshley). ♀ May 31, Four Mile Run, Virginia (W. L. McAtee).

Lygus communis var. **novascotiensis** Knight

1915 *Lygus invitus* Brittain (not Say)
Ent. Soc. Ont., Ann. rept. 46:65 (life history).
1916 *Lygus communis* var. *novascotiensis* Knight
Can. ent. 48:349.

Paler and more slender than the typical *communis*, but not differing materially in the male claspers.

Length 5.3 mm., greatest width 2 mm.; more slender and much paler than the typical *communis*; the two black rays on the pronotum small but distinct; hemelytra more yellowish brown than fuscous; lateral stripe of the body reddish or darkened with fuscous.

This is one of the varieties or races of *communis* which may be worked out from the forms inhabiting different plants, and is perhaps influenced somewhat by different external conditions. It breeds abundantly on apple in Nova Scotia, causing injury to the fruit similar to that of *Lygidea mendax* in New York State. The writer has spent four summers inspecting orchards in western New York, and has been unable to take any form of *communis* on the apple.

Described from several specimens received from William H. Brittain, of Truro, Nova Scotia, collected from apple at Kentville, Wolfville, and Smith's Cove, Nova Scotia, July 6 to 28, 1915. Brittain (1917) has just published another and more complete account of the life history and control of the species, which is becoming a serious pest to the apple in Nova Scotia.

Lygus univittatus new species

Resembling *laureae* in coloration, but smaller than that species; similar in size to large forms of *quercalbae*, but darker-colored and with reddish; distinguished by having a median longitudinal fuscous vitta on the scutellum; first segment of antenna black, and two blackish rays on the disk of the pronotum behind the calli; dark brownish black with reddish.

♀. Length 5.4 mm. *Head*: width across eyes 1.08 mm., vertex .51 mm., length .45 mm., height at base .65 mm.; yellowish brown marked with red, shining; tip of tylus and a small spot each side of vertex near front margin of eye fuscous; eyes reddish brown; vertex broad, sloping more abruptly from carina than in *laureae*. *Rostrum*, length 2.42 mm., reaching well beyond posterior margins of hind coxae, yellowish brown, apex blackish.

Antennae: segment I, length .6 mm., black, pale at joints; II, 1.94 mm., blackish at base, yellowish brown on apical half, tip darker; III, 1.11 mm., blackish; IV, .68 mm., blackish.

Pronotum: length 1.08 mm., width at base 2.02 mm., width at anterior angles 1 mm., collar .71 mm.; very similar in structure to *laureae*; dark yellowish brown tinged with reddish; a blackish ray behind each callus, in some cases including exterior half of callus, not so distinct as in *laureae*; dark fuscous brown around coxal cleft and extending behind it. *Scutellum* greenish yellow, with a longitudinal median fuscous vitta. *Sternum* brownish black or fusco-piceous; pleura nearly as dark as the sternum; orifice fuscous.

Hemelytra: greatest width 2.4 mm.; dark yellowish brown with fuscous and tinged with reddish, darkest on clavus and apices of corium and embolium, basal half of corium exterior to the cubitus paler; embolium reddish brown for its full length, darker on the apical one-third; cuneus pale flecked with reddish, apex distinctly red. *Membrane* fuscous, veins reddish; paler bordering apices of cells and tip of cuneus; an indistinct pale area near the margin just beyond apex of cuneus.

Legs: coxae yellowish brown darkened with fuscous; femora yellowish brown darkened with fuscous, posterior pair very dark fuscous brown, indistinctly annulated with paler near the apices; tibiae and spines yellowish; apical segments of the tarsi blackish, claws brownish.

Venter: fusco-piceous, yellowish or reddish on the vagina exterior, spiracles appearing as pale spots.

The two specimens of this very distinct and apparently rare species were taken to be forms of *quercalbae* at the time of collecting, and therefore no effort was made to locate the host plant or to get more material. It is regretted that the males are not available at this time for figuring the genital claspers.

Holotype: ♀ June 22, 1916, Portage, New York (H. H. Knight).

Paratype: ♀, taken with the type.

Lygus quercalbae new species

Resembles *omnivagus* but is more reddish brown in color; differs in being more robust, and in having a pale stripe thru the fuscous on the sides of the venter; similar to *semivittatus* in coloration of the venter, but differs in not having distinct fuscous spots behind the calli and in general by the more reddish color.

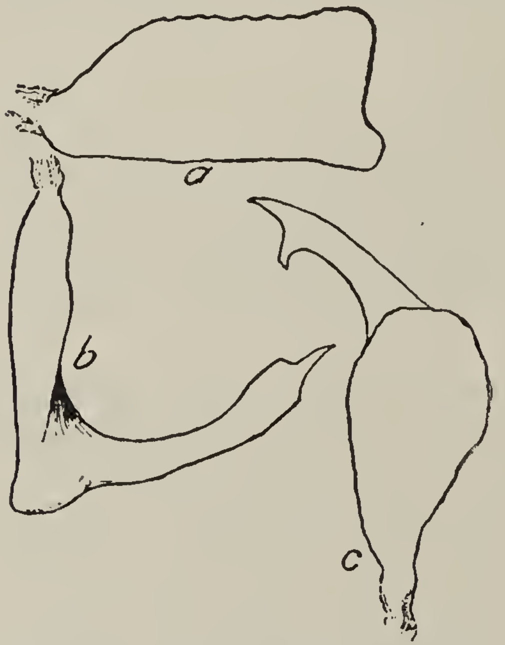

FIG. 199. LYGUS QUERCALBAE, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

♂. Length 5.7 mm. *Head*: width across eyes 1.11 mm., vertex .4 mm., length .44 mm., height at base .65 mm.; structurally very similar to that of *omnivagus*; yellowish brown, usually marked with reddish, tip of tylus fuscous. *Rostrum*, 1.85 mm., scarcely attaining posterior margins of hind coxae, yellowish brown marked with reddish, apex blackish.

Antennae: segment I, length .68 mm.; II, 2.17 mm., yellowish, apical half fuscous to blackish; III, 1 mm., yellowish tinged with fuscous; IV, .51 mm., only a shade darker than segment III.

Pronotum: length 1.17 mm., width at base 2.08 mm., width at anterior angles 1 mm., collar .68 mm.; structurally like that of *omnivagus*; yellowish brown, in some cases darkened on the calli but never with distinct spots just behind as in *semivittatus*; coxal cleft and just behind it fuscous, in some cases with reddish just above; in rare cases the whole disk and dorsum of the insect is evenly darkened, thus resembling *caryae*. *Scutellum* yellowish brown, slightly darker at the sides. *Sternum* fuscous, tinged with reddish or yellowish at the sides; pleura fuscous margined with reddish; orifice fuscous.

Hemelytra: greatest width 2.4 mm., structurally and in color much like those of *omnivagus*; yellowish brown tinged with reddish; clavus and apical half of corium dark brownish tinged with reddish, more reddish at apex of embolium; cuneus pale tinged with yellowish, in some cases a touch of red at the apex. *Membrane* fuscous, pale marks somewhat similar to those of *semivittatus*.

Legs: coxae pale, a touch of reddish at the base; femora greenish yellow or tinged with brownish, posterior pair with all but the base dark reddish with fuscous, twice annulated near the apices with fuscous-red; tibiae greenish yellow, spines yellowish; tips of tarsi fuscous, claws yellowish.

Venter: marked very much as in *semivittatus* but with more reddish; pale beneath, with a pale stripe on the sides bounded by fuscous and reddish stripes; genital claspers (fig. 199) very distinctive of the species; claspers showing a close relation to those of *semivittatus*, but the forked tip on the inner hook of the dextral clasper separates the two species at once.

♀. Length 5.6 mm., width 2.6 mm.; more robust than the male, but very similar in coloration; larger and more reddish than *omnivagus* and *semivittatus*; distinguished by pale stripe on the sides of the venter and by lacking fuscous spots behind the calli, at the same time being more reddish than *semivittatus*.

The species breeds rather abundantly on white oak (*Quercus alba*), and only on this tree so far as the writer has been able to determine; hence the name.

The nymphs hatch with the bursting of the buds and feed thereafter on the tender foliage. On May 20, 1916, many nymphs were observed to be in the third instar. This was shortly after there had been an exceedingly heavy downpour of rain and the writer was interested to learn how the insects behaved in time of flood. It was seen that the tiny nymphs found ample cover by retreating under the loosened bud scales that clung to the unfolding new growth. It was observed also that the nymphs spent the nights, as well as damp, cold days, under cover of the bud scales.

Up to the fourth instar the nymphs are greenish yellow but later they become tinged with pink. In the last instar the wing pads become brownish and the body is tinged with pink. In western New York the adults mature about the middle of June and continue on the white oak trees up to the middle of July. The eggs are laid mostly in late June and early July in the twigs of the host plant; there they pass the winter, and the nymphs come forth with the bursting of the buds in spring.

Holotype: ♂ June 14, 1914, Ithaca, New York (H. H. Knight).

Allotype: with the type.

Paratypes: ♂ 2 ♀ June 7, ♂ June 13, 2 ♂ 3 ♀ June 14, ♀ July 23, Ithaca, 63 ♂ ♀ June 23, Conesus Lake, ♂ 9 ♀ June 21, 4 ♀ June 27, Portage, ♀ July 4, Four Mile, ♀ July 13, Batavia, New York; all collected by the writer. ♂ July 13, Springfield, ♂ June 11, 2 ♂ June 17, Boston, Massachusetts (H. M. Parshley). ♂ June 12, ♀ June 28, Beaver Dam, Wisconsin (W. E. Snyder). ♀ July 1, Bluemont, Virginia (W. L. McAtee). ♂♀ June 23, 1885, Ithaca, New York (H. E. Grotecloss and E. H. Sargent).

Lygus semivittatus new species

Resembles *omnivagus* in coloration of the hemelytra; two small fuscous marks on the disk behind the calli, very suggestive of *caryae* var. *subfuscus* but differing in having a pale stripe thru the fuscous on the sides of the venter; similar to *quercalbae* in having the venter fuscous brown with a pale stripe dividing the dark color, but distinguished at once by the fuscous marks on the pronotum; males easily distinguished by the genital claspers.

♂. Length 5.3 mm. *Head*: width across eyes 1.06 mm., vertex .38 mm., length .42 mm., height .63 mm.; yellowish brown slightly tinged with reddish, apical half of tylus blackish, eyes blackish; similar to head of *quercalbae* in structure.

Antennae: segment I, length .63 mm., yellowish; II, 2.02 mm., yellowish brown, apical one-third brownish to dark fuscous; III, 1.14 mm., yellowish faintly tinged with fuscous; IV, .57 mm., slightly darker than segment III.

Pronotum: length 1.65 mm., width at base 1.88 mm., width at anterior angles .85 mm., collar .68 mm.; similar in structure to those of *quercalbae* and *omnivagus*; yellowish brown, a small fuscous spot behind each callus scarcely forming a ray; fuscous on sides to height of coxal cleft, with a small narrow fuscous or reddish line just above. *Scutellum* yellowish brown, darker brown or fuscous at the sides. *Sternum* fuscous, in some cases slightly yellowish beneath; pleura and orifice fuscous.

Hemelytra: greatest width 2.28 mm.; dark brownish to fuscous, very similar to those of *omnivagus*; usually yellowish on the basal half of the embolium and narrow adjacent margin of the corium; cuneus pale or tinged with yellowish. *Membrane* fuscous, bordering the cuneus and veins paler; a small pale spot near the margin beyond the apex of the cuneus, also paler fuscous in the middle of the membrane.

Legs: coxae pale yellowish, a touch of reddish brown at base; femora pale greenish yellow, the posterior pair brownish to dark brown, indistinctly annulated with darker near apices, yellowish at base; tibiae greenish yellow, spines yellowish brown; apices of tarsi brownish, claws yellowish.

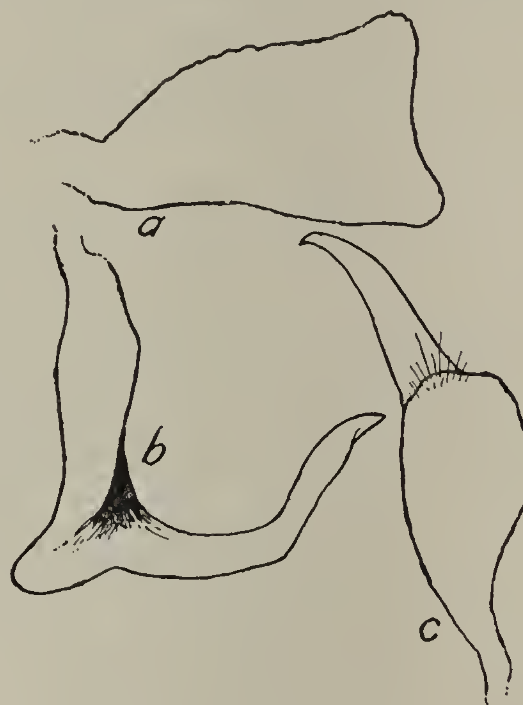

FIG. 200. LYGUS SEMIVITTATUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Venter: dark brownish to fuscous, pale beneath except on genital segment, a pale longitudinal stripe thru the fuscous on the sides; genital segment with a yellowish spot on the sides at base of claspers; genital claspers (fig. 200) very distinctive of the species; sinistral clasper with the lateral aspect broad, upper apical angle bent outward; the long slender inner hook of the dextral clasper sharp and curved at the tip.

♀. Length 5.4 mm., width 2.2 mm.; very similar to the male in coloration but with less fuscous on the hemelytra; most easily confused with *caryae* var. *subfuscus*, but distinguished by the longitudinal pale stripe running thru the fuscous color on the sides of the venter.

The type specimens were collected by the writer on white oak, but the species has not been found abundant anywhere even on the oaks.

Holotype: ♂ June 13, Ithaca, New York (H. H. Knight).

Allotype: with the type.

Paratypes: 2 ♀ June 13, Ithaca, ♂ June 23, Conesus Lake, ♂ June 22, ♂ June 27, Portage, New York; all collected by the writer. ♂ June 13, Pinelawn, Long Island (C. E. Olsen). ♂ May 31, Four Mile Run, Virginia (W. L. McAtee).

Lygus omnivagus new species

Very much resembles forms of *semivittatus* and *quercalbae*, also might be confused with the females of *canadensis* and pale forms of *caryae* var. *subfuscus*; male is easily distinguished by the long, broad, upward-curved, sinistral clasper.

♂. Length 5.4 mm. *Head*: width across eyes 1.03 mm., vertex .41 mm., length .4 mm., height at base .6 mm.; yellowish brown, tip of tylus and lorae darkened with fuscous, eyes dark brownish; carina slightly arcuate, indistinct impression just before on the vertex. *Rostrum*, length 2.17 mm., reaching slightly beyond posterior margins of hind coxae, yellowish, apex darkened.

Antennae: segment I, length .63 mm., yellowish; II, 2.08 mm., yellowish, apical one-fourth blackish; III, 1.25 mm., yellowish, only slightly fuscous toward the tip; IV, .74 mm., pale fuscous.

Pronotum: length 1.03 mm., width at base 1.88 mm., width at anterior angles .88 mm., collar .65 mm.; yellowish brown, in some cases darker on the disk but never with blackish rays; fuscous on the sides behind the coxal cleft; calli apparent as slightly raised, shining ovals; finely and shallowly punctate, fine yellowish pubescence. *Scutellum* pale yellowish, in some cases darkened with brownish at the sides; finely transversely rugose, fine yellowish pubescence. *Sternum* pale yellowish beneath, sides fuscous; pleura and orifice fuscous.

Hemelytra: greatest width 2.22 mm.; clavus brownish to dark brownish or blackish in some forms; corium dark brownish with fuscous, basal angle yellowish, usually paler bordering the embolium except on the apical one-third; embolium yellowish, dark brownish near apex where dark color of corium crosses; cuneus pale, slightly tinged with yellowish; shallowly punctate, more or less scabrous, prominent yellowish pubescence. *Membrane* mostly pale marked with fuscous; apical half of cells, an area in middle of membrane and extending toward apex, a spot each side near tip of cuneus, and a smaller one beyond near the margin, fuscous.

Legs: pale yellowish tinged with greenish; posterior femora dark brownish on the apical half, two dark rings contrasted with pale near the apices; tibial spines yellowish; tips of tarsi dark brownish, claws yellowish brown.

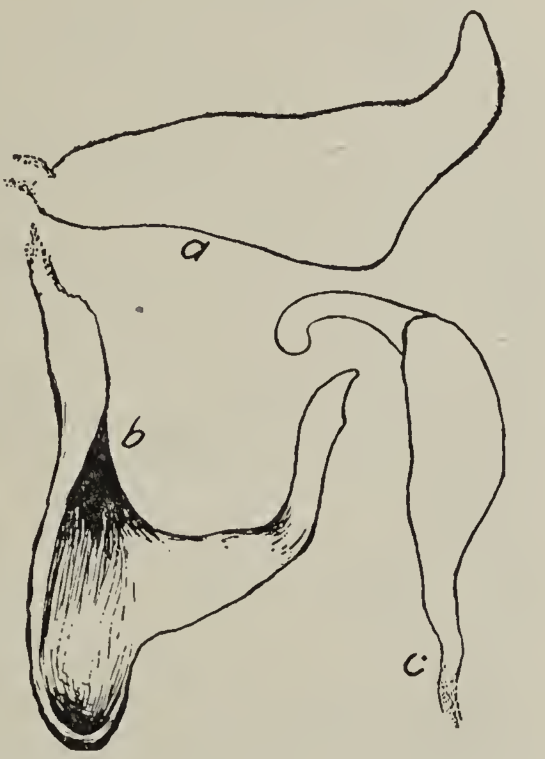

FIG. 201. LYGUS OMNIVAGUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Venter: pale or yellowish beneath, sides and genital segment dark brownish with fuscous; pale pubescence noticeable; genital claspers (fig. 201) very distinctive of the species; the broad upcurved sinistral clasper extending beyond the tip of the body, easily seen without the aid of a lens.

♀. Length 5.4 mm., width 2.5 mm.; usually paler than the male, more yellowish brown; never with reddish as in *quercalbae*, nor with fuscous marks on the pronotum as in *semivittatus* or in *caryae* var. *subfuscus*; the female of *canadensis* has the apical one-third of the second antennal segment more distinctly black and the fuscous spot on the apex of the corium smaller and not invading the pale embolium.

This species is commonly found breeding on several plants, hence its name. It is found most abundant on the oaks, particularly on *Quercus alba*, *Q. rubra*, *Q. coccinea*, *Q. prinus*, and *Q. velutina*. The writer has also reared specimens from chestnut (*Castanea dentata*), *Cornus florida*, *Cornus circinata*, and *Viburnum acerifolium*, tho the species is not found so frequently on these plants as on the oaks. The nymphs hatch with the unfolding of the buds and feed on the tender foliage. They are greenish yellow in color, the wing pads becoming darker as they develop. In western New York the adults usually begin to emerge about June 10, and by June 22 the majority have matured. The eggs are laid in the tender twigs during July, and by the first week in August most of the adults have died.

Holotype: ♂ July 23, Ithaca, New York (H. H. Knight).

Allotype: with the type.

Paratypes: ♂ ♀ June 7, 6 ♂ 4 ♀ June 14, 4 ♂ June 16, 3 ♂ 3 ♀ July 23, 5 ♂ July 24, 9 ♂ 5 ♀ July 26, Ithaca, 18 ♂ ♀ June 21, 63 ♂ ♀ June 27, ♂ ♀ August 9, Portage, 68 ♂ ♀ June 23, Conesus Lake, ♂ 3 ♀ June 15, 3 ♂ June 16, ♂ 2 ♀ June 19 (reared from *Cornus florida*), 13 ♂ ♀ June 19–20 (reared from *Cornus circinata*), ♂ 3 ♀ June 20, 4 ♂ ♀ June 21, ♂ 2 ♀ June 25, ♂ July 1, ♀ July 5, ♀ July 10, ♂ 2 ♀ July 14, 2 ♀ July 30, ♂ 5 ♀ August 5, ♂ ♀ August 13, Batavia, 82 ♂ ♀ July 4–5, Four Mile, New York; all collected by the writer. ♂ 8 ♀ July 4–7, Bayshore, Long Island, 5 ♂ 9 ♀ July 29, Pigeon Cove, Massachusetts (C. E. Olsen). ♂ July 27, Lake George, New York (A. K. Fisher). ♂ July 20, Gloucester, Massachusetts (W. L. McAtee). ♂ July 10, Woods Hole, Massachusetts. ♂ ♀ June 8, New Haven, Connecticut (W. E. Britton). One specimen June 11, one June 24, New Haven, Connecticut (B. H. Walden). ♂ July 5, Branford, Connecticut (Butrick). 3 ♂ ♀ June 15, Danbury, Connecticut (C. W. Johnson). June 5, Double Beach, Connecticut (H. L. Viereck). July 25, Buttonwoods, Rhode Island. ♂ ♀ July 3, Hanover, New Hampshire; ♂ July 11, Ascutney Mountain, ♂ June 22, Burlington, Vermont; all collected by C. W. Johnson. 2 ♂ 2 ♀ July 24, 2 ♂ ♀ August 7, Parry Sound, Ontario, Canada (H. S. Parish). ♂ July

10, Hot Springs, ♂ ♀ August 2, Bath County, Virginia, altitude 3500 feet (Morgan Hebard). ♂ July 14, Black Mountains, North Carolina (Beutenmuller). ♂, Lake Toxaway, North Carolina (Mrs. A. T. Slosson).

Lygus johnsoni new species

Resembles *communis* in having two prominent black spots on the pronotum, but is distinguished at once by the clear outer margin and the dark fuscous inner half of the corium; the long, thick, upturned prong of the left male clasper is distinctive of the species.

♂. Length 5.7 mm. *Head*: width across eyes 1.08 mm., vertex .44 mm., length .48 mm., height at base .65 mm.; greenish yellow, shining; tylus blackish shading paler at the base, juga and lorae shaded with fuscous, eyes dark brownish. *Rostrum*, length 2.28 mm., reaching the posterior margins of the hind coxae, yellowish, the extreme tip blackish.

Antennae: segment I, length .68 mm., dark fuscous to blackish; II, 2.08 mm., black, a very narrow pale ring at base; III, 1.28 mm., pale, lightly infuscated; IV, .85 mm., only slightly darker than segment III.

Pronotum: length .97 mm., width at base 1.85 mm., width at anterior angles .85 mm., collar .68 mm.; greenish yellow tinged with brownish; a black spot behind each callus, rarely if ever extending back more than halfway to the basal margin; sides up to height of coxal cleft, extending forward, and around the lower half of the collar, blackish. *Scutellum* greenish yellow, in some cases narrowly infuscated along the claval margin, very finely transversely rugulose. *Sternum* yellowish or greenish beneath; pleura fuscous to blackish, forming part of a black stripe that extends the full length of the body.

Hemelytra: greatest width 2.3 mm., closely and minutely punctured, clothed with rather prominent yellowish pubescence; yellowish brown, clavus frequently with fuscous bordering the scutellum, fuscous or blackish in the suture separating the clavus and the corium; corium yellowish brown bordering the claval margin, pale to clear on the outer margin exterior to the cubital vein, the middle part with an elongate wedge of dark fuscous or black; embolium pale to yellowish or greenish in fresh specimens; cuneus clear, often greenish along the outer margin but never fuscous. *Membrane* dark fuscous within the cells, flecked with pale at base, veins pale brownish; a dark fuscous spot just beyond apex of cuneus, a second paler one along the margin halfway to the apex, pale areas surrounding these spots and along apices of cells.

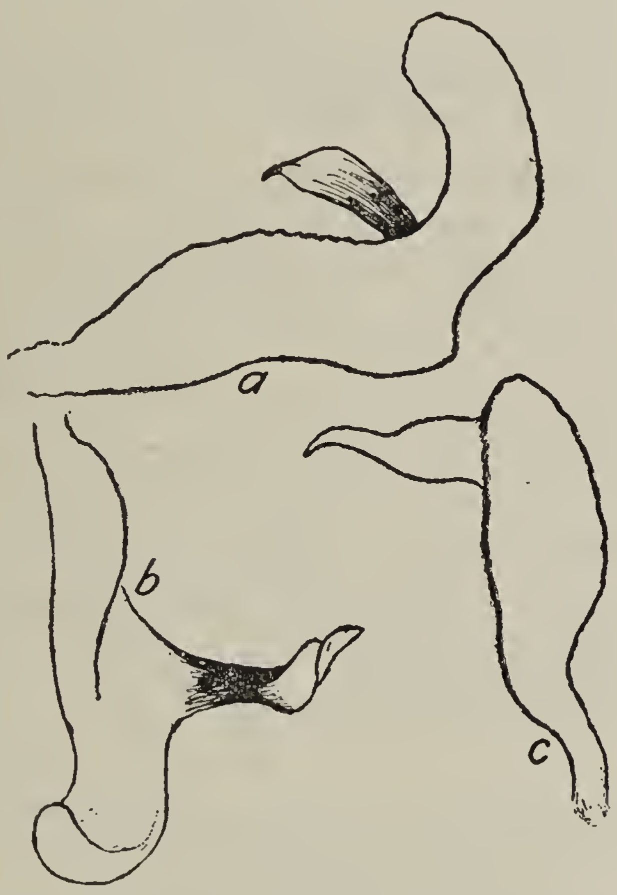

Fig. 202. LYGUS JOHNSONI, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Legs: pale yellowish or with greenish, the posterior femora with two fuscous rings near the apices joining beneath with a longitudinal fuscous bar.

Venter: pale beneath with a broad lateral blackish stripe; genital segment fuscous to blackish with yellowish beneath, shining, the claspers (fig. 202) yellowish brown or amber-colored.

♀. Similar to the male in color and only slightly more robust.

This unusual new species is dedicated to C. W. Johnson, who collected the type specimens and who to the writer's knowledge was the first to preserve representatives of this interesting species. During the season of 1916 the writer found the species in New York State and was able to make observations on the life history.

Holotype: ♂ June 17, 1909, Middletown, Connecticut (C. W. Johnson).

Allotype: topotypic; returned to Mr. Parshley.

Paratypes: 2 ♀, topotypic; ♀ June 23, St. Johnsbury, Vermont (C. W. Johnson). 9 ♂ 13 ♀ June 23, Conesus Lake, ♂ 2 ♀ July 18, 9 ♀ July 29, 2 ♀ July 30, 2 ♀ August 1, Batavia, 7 ♂ 44 ♀ July 27, McLean, New York; all collected by the writer.

The specimens collected at Conesus Lake were taken on hornbeam (*Carpinus caroliniana*) in a small ravine along the west shore of the lake near Long Point. On that date, June 23, several of the specimens were teneral and two or three were observed to feed on the fruit spikes. The Batavia specimens were likewise taken on Carpinus which grew in a thick, cool, swampy woods. At McLean, on July 27, the females were in the height of egg-laying. Practically all of the fifty-one specimens taken there were picked off the trunks and large limbs of *Carpinus caroliniana*, where they were attracted to lay eggs. Three females were observed to oviposit, and in each case the eggs were being inserted into the soft, punky stubs formed by the breaking-off of old dead limbs. In examining such stubs the writer found freshly laid eggs and the old empty eggshells in abundance. When the nymphs hatch in the spring they evidently work their way up from such points to the tender foliage. The indications are that this is a northern species, for the writer has found it only in a few cool, damp situations. and only under such conditions does it appear to persist in New York.

Lygus belfragii Reuter

1876 *Lygus belfragii* Reuter
Caps. Amer. bor., p. 71.

Elongate, green or greenish yellow, clavus brownish and tinged with fuscous and bronze, apex of the corium with a triangular fuscous or blackish patch, membrane fuscous longitudinally thru the middle; in general appearance resembling *confusus*, *alni*, and females of *tiliae*.

♂. Length 5.6–6 mm. *Head*: width across eyes 1.08 mm., vertex .35 mm., length .4 mm., height at base .63 mm.; greenish yellow or yellowish brown, carina prominent, vertex slightly sulcate along the median line, eyes dark brown to black. *Rostrum*, length 1.9 mm., scarcely attaining the posterior margins of the hind coxae, yellowish brown, darker at the apex.

Antennae: segment I, length .66 mm., greenish yellow; II, 2.19 mm., yellowish to yellowish brown, usually infuscated toward apex; III, 1.14 mm., pale fuscous; IV, .74 mm., only slightly darker than segment III; segments clothed with very fine pale pubescence.

Pronotum: length 1.05 mm., width at base 1.88 mm., width at anterior angles .88 mm., collar .63 mm.; greenish yellow, frequently bright green on the lateral margins with the disk more brownish and tinged with bronze; calli rather indistinct but outlined by a slightly impressed line, very finely and closely punctured, with very fine pubescence. *Scutellum* green or faded to greenish yellow or darker, finely pubescent, very finely transversely rugose; mesoscutum usually brownish and but narrowly exposed. *Sternum* yellowish, pleura frequently bright green.

Hemelytra: greatest width 2.28 mm.; clavus yellowish brown tinged with bronze, darker along the cuneus and suture; corium greenish to yellowish, translucent bordering the embolium, strongly fuscous at apex and forming a triangular spot the base of which never extends across the embolium; embolium and cuneus bright green but in some cases fading to yellowish; finely punctured and with very fine yellowish pubescence. *Membrane* with a fuscous spot in the center, which widens toward the apex to include the whole tip; cells clouded within the apices and longitudinally between the two larger ones, joining at base with the darkened apex of the corium; veins at apices of the cells pale, as is the membrane each side of the darkened middle part, a small dusky spot within the pale area near the tip of the cuneus.

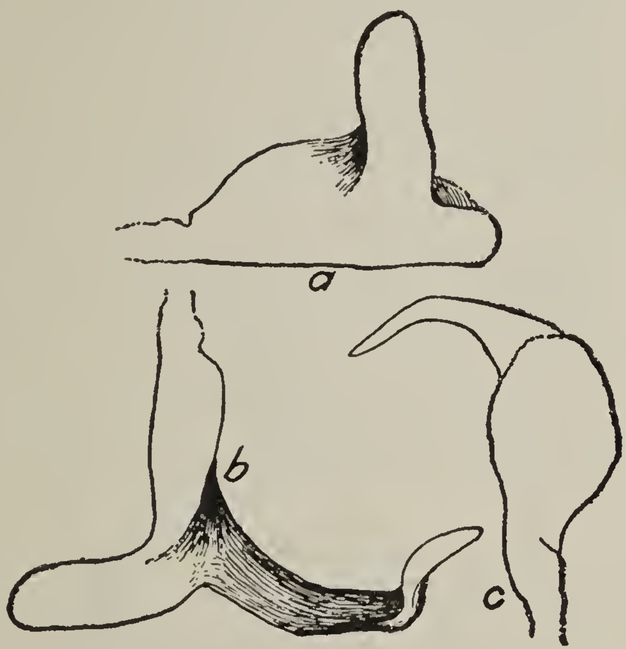

FIG. 203. LYGUS BELFRAGII, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Legs: greenish yellow, apices of the posterior femora in some cases indistinctly marked with two fuscous annuli; tibial spines pale brownish, the extreme apices of the tibiae darker; apical tarsal segment dark brown to fuscous.

Venter: green or greenish yellow; genital claspers very distinct, the left clasper having a blunt prong that extends at right angles to the body (fig. 203).

♀. Length 5.5 to 5.8 mm.; similar to the male in coloration, but slightly more robust.

The type material of this species was collected in New York by Mr. Belfrage, after whom the species was named by Reuter.

In western New York the species breeds abundantly on mountain maple (*Acer spicatum*), and to some extent on *Viburnum acerifolium* and *Cornus alternifolia*. The species is frequently attracted to the flowers of poison hemlock (*Conium maculatum*) for feeding, and in this way 58 specimens were taken on July 31, 1915.

Records: 57 ♂ ♀ June 27, Portage, New York, with nymphs, from *Acer spicatum*; 22 ♂ ♀ July 4, Four Mile, New York, from both *A. spicatum* and *Viburnum acerifolium*; 2 ♂ 2 ♀ June 26, Wyoming, New York, bred from *Cornus alternifolia*; ♂ June 23, Conesus Lake, 17 ♂ ♀ July 26, Ithaca, ♂ ♀ July 27, McLean, ♂ July 6, 2 ♀ July 30, 58 ♂ ♀ July 31, 3 ♀ August 30, Batavia, New York; all collected by the writer. ♀ August 2–9, Gowanda, New York (E. P. Van Duzee). ♀, Red Rock, Luzerne County, Pennsylvania (Wm. T. Davis). 2 ♂ June 17, Boston, Massachusetts (H. M. Parshley). ♂ ♀ July 8, Norwich, Vermont, ♀ July 14, Capens, ♀ July 19, Machias, Maine (C. W. Johnson). ♂ ♀ July 10 to August 7, Parry Sound, Ontario, Canada (H. S. Parish).

Lygus clavigenitalis new species

Yellowish brown, with darker brown on the clavus and the apex of the corium; resembling most the female of *tiliae* and both sexes of *inconspicuus*; differs from those species in lacking the green, in having the pronotum evenly shaded with yellowish brown, and in being more brownish than fuscous on the hemelytra; male claspers very distinctive of the species.

♂. Length 4.8 mm. *Head*: width across eyes 1 mm., vertex .4 mm., length .4 mm., height .51 mm.; yellowish brown, eyes dark brownish to blackish; carina prominent, slightly arcuate, impressed on the vertex but not so distinct as in *inconspicuus*. *Rostrum*, length 1.57 mm., scarcely attaining posterior margins of hind coxae, yellowish brown, apex darker.

Antennae: segment I, length .57 mm., yellowish; II, 1.77 mm., yellowish to yellowish brown, apex in some cases darker; III, 1.08 mm., pale fuscous; IV, .71 mm., scarcely darker than segment III.

Pronotum: length 1 mm., width at base 1.71 mm., width at anterior angles .83 mm., collar .6 mm.; yellowish brown, paler on the sides; shallowly and finely punctate, fine pale yellowish pubescence. *Scutellum* yellowish, more brownish at the margins, very finely transversely rugose. *Sternum* pale yellowish; orifice pale.

Hemelytra: greatest width 2.17 mm.; clavus uniformly brownish; corium yellowish, apex dark brownish and not extending onto the embolium; embolium and cuneus pale yellowish translucent, in life tinged with green; minutely and shallowly punctate, appearing slightly scabrous, fine yellowish pubescence. *Membrane* fuscous brown, paler bordering the cuneus, the veins, and an indistinct spot near the margin beyond the apex of the cuneus.

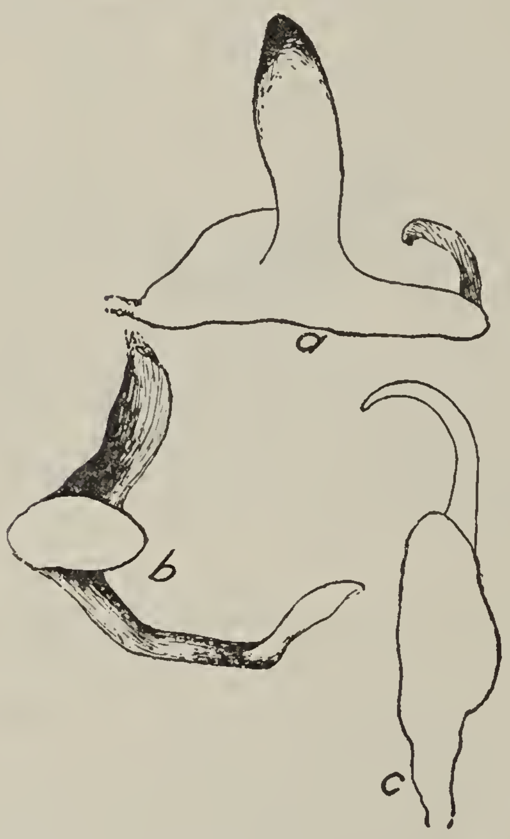

FIG. 204. LYGUS CLAVIGENITALIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Legs: pale yellowish or greenish, posterior femora in some cases more brownish; tibiae greenish, spines brownish; apices of the tarsi fuscous, claws brownish.

Venter: yellowish, more greenish in life; genital claspers (fig. 204) very distinctive of the species; claspers resembling most those of *belfragii*, the tip of the club sharper and turning inward, instead of outward as is the case in *belfragii*.

♀. Length 5.1 mm., width 2.3 mm.; slightly larger and more robust than the male but very similar in coloration; most likely to be confused with the females of *tiliae* and *inconspicuus*, also resembling the pale forms of *viburni* and *geneseensis*; points of difference are: *inconspicuus* is more greenish and the fuscous marks on the clavus and the apex of the corium are more contrasting; *tiliae* is more green, particularly the pronotum, and the scutellum is darkened with fuscous; *viburni* has nearly the whole corium brownish, the apex of the embolium darkened, and the apical half of the antennae fuscous; *geneseensis* is very similar to *viburni* except that the antennae are not fuscous, but the embolium is darkened to even a greater extent.

Holotype: ♂, Waltham, Massachusetts.

Allotype: topotypic.

Paratypes: 4 ♂ July 9, Portland, Maine (E. P. Van Duzee). ♂ July 4, Beltsville, Maryland (W. L. McAtee).

Mr. McAtee took his specimen on *Alnus rugosa*, which may possibly be the food plant of this species.

Lygus hirticulus Van Duzee

1912 *Lygus tenellus* Van Duzee
Buffalo Soc. Nat. Sci., Bul. **10**:484.
1916 *Lygus hirticulus* Van Duzee
Check list Hemip. N. Amer., p. 40. (Name preoccupied.)

Rather small, the male dark ferrugino-testaceous, more evenly testaceous in the female, the legs, antennae, and pronotum usually lighter-colored; resembles *fagi*, but the males are easily distinguished by the genital claspers; occasionally the males may be entirely dark fuscous or blackish excepting the legs and antennae.

♂. Length 4.8 mm. *Head*: width across eyes .94 mm., vertex .4 mm., length .4 mm., height at base .57 mm.; dark brownish; lorae, bucculae, juga, and frequently the vertex, darkened with fuscous; smooth shining, an impressed triangle on the vertex just before the carina. *Rostrum*, length 1.78 mm., attaining the posterior margins of the hind coxae, yellowish brown, apex blackish.

Antennae: segment I, length .65 mm., yellowish brown; II, 2.22 mm., greenish yellow to brownish; III, 1.28 mm., yellowish; IV, .85 mm., yellowish and slightly tinged with fuscous; all the segments with fine pale pubescence.

Pronotum: length .94 mm., width at base 1.68 mm., width at anterior angles .83 mm., collar .6 mm.; uniformly colored with dark brownish, the sides to height of coxal cleft fuscous; disk in some cases darkened with fuscous, and in unusually dark forms almost blackish as is the head; pubescence yellowish brown, calli and punctuation similar to those in *tiliae* and *belfragii*. *Scutellum* dark brownish to blackish; yellowish pubescent, very finely transversely rugose; mesoscutum usually brownish. *Sternum* yellowish brown beneath, sides darkened with fuscous.

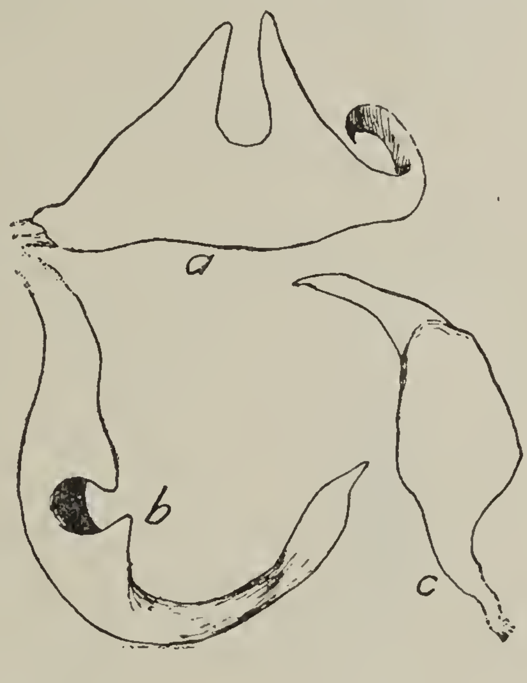

FIG. 205. LYGUS HIRTICULUS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

Hemelytra: greatest width 2.28 mm.; ferrugino-testaceous, costal margin usually paler; cuneus brownish to pale fuscous, darkest on the basal half; densely clothed with fine yellowish brown pubescence. *Membrane* pale fuscous, evenly shaded with pale yellowish brown in the female.

Legs: greenish yellow to yellowish brown; tibial spines of the same color; apices of tarsi slightly darkened.

Venter: ferruginous on the sides, more brownish beneath; genital claspers (fig. 205) very distinctive of the species.

♀. Length 5.3 mm., width 2.3 mm.; slightly larger and more robust than the male; uniformly colored with yellowish brown or in some cases dark brown, hemelytra rarely much darker than the pronotum; female could easily be confused with *fagi*, but may be distinguished by the membrane, which is uniformly and faintly tinged with fuliginous and is never dark as in *fagi*.

The species appears to breed sparingly on several plants and is never numerous on any particular plant. The writer has reared specimens from chestnut, beech, and woodbine. The life history is similar to that of other closely related species: the insect passes the winter in the egg stage on the host plant, hatching with the unfolding of the leaves; nymphs feed on the tender foliage and mature about the middle of June; the eggs are laid during July, and most of the adults are dead by the first week in August.

Records: Numerous specimens June 16 to August 1, Batavia, 2 ♂ ♀ June 21, ♂ ♀ August 9, Portage, 9 ♂ 5 ♀ June 16–25, Wyoming, numerous specimens July 4–5, Four Mile, ♂ ♀ June 23, Conesus Lake, 3 ♂ 6 ♀ July 24, Ithaca, New York; all collected by the writer.

Lygus canadensis new species

Resembles *omnivagus* in general appearance; yellowish brown, clavus and apex of the corium dark brownish, margins of the scutellum sometimes brownish.

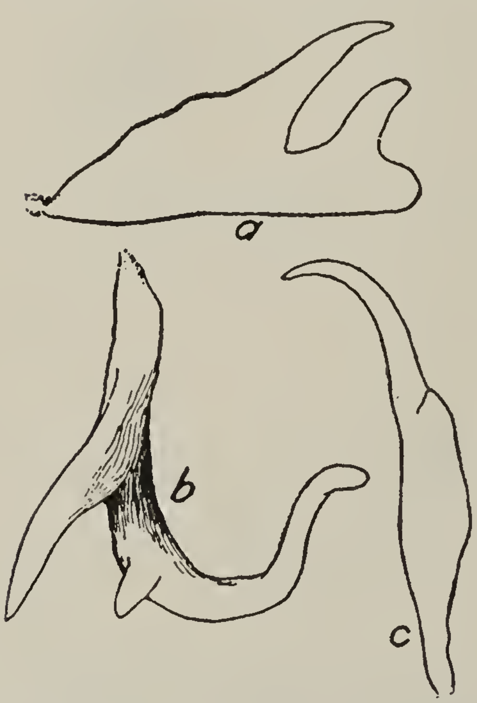

Fig. 206. LYGUS CANADENSIS, MALE GENITAL CLASPERS

a, Left clasper, lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

♂. Length 5.5 mm. *Head*: width across eyes .97 mm., vertex .38 mm., length .43 mm., height at base .6 mm.; yellowish brown, eyes dark brown; carina arcuate, an impressed line at each side extending to form a small impressed triangle before the carina. *Rostrum*, length 2 mm., scarcely reaching the posterior margins of the hind coxae, green to yellowish, apex fuscous.

Antennae: segment I, length .68 mm., yellowish; II, 2.05 mm., pale yellowish, apical one-third fuscous to blackish; III, 1.22 mm., yellowish, lightly infuscated; IV, .8 mm., slightly darker than segment III.

Pronotum: length .97 mm., width at base 1.63 mm., width at anterior angles 1 mm., collar .63 mm.; yellowish brown, in some cases darker on the base of the disk. *Scutellum* yellowish, margins brownish, indistinctly rugulose, nearly smooth. *Sternum* and pleura yellowish.

Hemelytra: greatest width 2.08 mm.; clavus dark brownish, embolium pale yellowish, corium pale yellowish with the apical one-third dark brownish; cuneus pale; finely and closely punctured, very fine yellowish pubescence. *Membrane* infuscated, paler within the base of the cells and surrounding a small fuscous spot close to the tip of the cuneus.

Legs: greenish yellow to yellowish brown; apices of the posterior femora twice annulated with pale fuscous; apices of the tarsi fuscous.

Venter: yellowish to yellowish brown; genital claspers (fig. 206) very distinctive of the species.

♀. Slightly more robust than the male, and usually with less dark brown.

Holotype: ♂ July 10, Parry Sound, Ontario, Canada (H. S. Parish).

Allotype: topotypic.

Paratypes: ♂ ♀, topotypic. ♂ July, Polk County, Wisconsin (Baker), received from Dr. William A. Hilton.

This is apparently a species of northern distribution, but will doubtless be taken in New York State.

Lygus canadensis var. **binotatus** new variety

Male genital claspers similar to those of *canadensis*, but this form differs in having a very distinct ray behind each callus and extending to near the basal margin of the disk; scutellum appears more convex and with dark brownish at the sides.

Described from a single male specimen, collected on June 18 at Havith, New Jersey, by Wm. T. Davis.

Lygus ostryae new species

Resembles the pale and yellowish forms of *belfragii*, usually slightly larger and strongly yellowish brown in color; males are readily distinguished by the two unusually large upturned prongs of the left clasper.

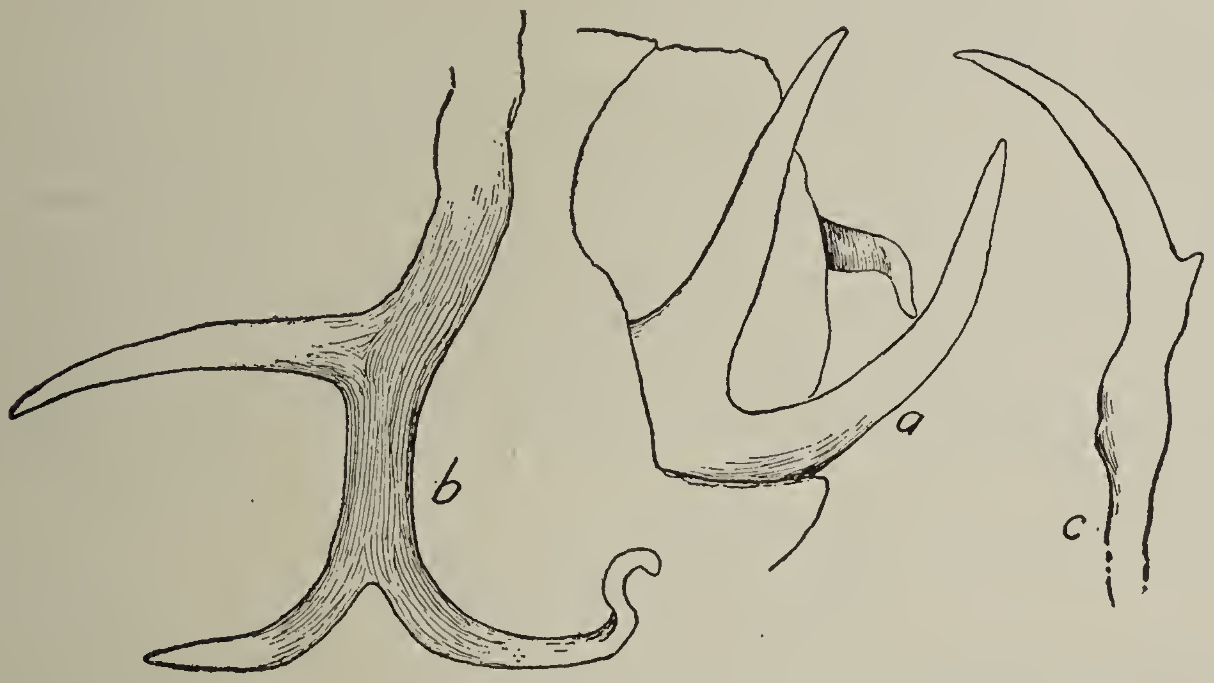

FIG. 207. LYGUS OSTRYAE, MALE GENITAL CLASPERS
a, Genital segment, left lateral aspect; b, left clasper, dorsal aspect; c, right clasper, ventral aspect

♂. Length 5.5–6 mm. *Head*: width across eyes 1.05 mm., vertex .37 mm., length .45 mm., height at base .63 mm.; yellowish brown, shining, eyes dark brownish; basal carina and other structures nearly as in *belfragii*. *Rostrum*, length 2.08 mm., reaching to the posterior extremities of the hind coxae, pale yellowish to brown, apex dark brown.

Antennae: segment I, length .74 mm., same color as head; II, 2.25 mm., yellowish with apex fuscous; III, 1.25 mm., yellowish with apical half slightly infuscated; IV, .71 mm., infuscated; all the segments with very fine pubescence.

Pronotum: length 1 mm., width at base 1.85 mm., width at anterior angles .85 mm., collar .65 mm.; yellowish brown, paler at the lateral margins and in some cases at the center of the disk; punctures evident but shallow, more or less transversely confluent. *Scutellum* pale yellowish brown, darker on the margins, transversely rugulose. *Sternum* and whole undersurface yellowish, in some cases tinged with brown.

Hemelytra: greatest width 2.36 mm., yellowish pubescence rather prominent; embolium and basal half of the corium pale yellowish, clavus and apical half of the corium brownish to dark brown; cuneus clear tinged with yellow. *Membrane* and veins yellowish, lightly infumed with fuscous; in the darkest specimens the cells, the center of the membrane, and a small transverse spot beyond the apex of the cuneus, dark brown with fuscous.

Legs: pale yellowish brown; spines on the tibiae darker yellowish brown; tarsi yellowish, apices fuscous; in dark specimens the posterior femora are annulated near the apices with two narrow fuscous bands.

Venter: yellowish brown, in some cases darker along the lateral line; genital segment shining, genital claspers (fig. 207) larger and more striking than those of any other species here considered, the left clasper with two unusually long upturned prongs.

♀. Length 6 mm.; similar to the male but broader and slightly larger.

The species breeds on the hop hornbeam (*Ostrya virginiana*) in western New York, and has a life history very similar to that of *communis* and of *invitus*.

Holotype: ♂ June 25, 1915, Batavia, New York (H. H. Knight).

Allotype: with the type.

Paratypes: 33 ♂ ♀ June 25, ♀ June 30, ♂ July 1, ♂ July 5, ♂ July 10, ♂ July 30, ♂ ♀ August 13, Batavia, 5 ♂ 2 ♀ June 27, 3 ♀ August 9, Portage, ♂ 2 ♀ July 4, Four Mile, 22 ♂ ♀ June 23, Conesus Lake, ♂ June 27, Honeoye Falls, 3 ♂ June 16, 2 ♀ July 23, Ithaca, New York; all collected by the writer. ♀ August 2, Gowanda, New York (E. P. Van Duzee). A large series of specimens, August 6–8, Parry Sound, Ontario, Canada (H. S. Parish). ♂ June 20, North Adams, Massachusetts, ♀ July 8, Norwich, Vermont (C. W. Johnson). ♂ July 4, Brookline, Massachusetts.

Lygus laureae new species

Resembles *communis* but is larger; yellowish brown with fuscous, tinged with pink; form of the genital claspers very unusual and distinctive.

♂. Length 5.4–6.2 mm. *Head*: width across eyes 1.11 mm., vertex .43 mm., length .51 mm., height at base .64 mm.; yellowish brown tinged with reddish, shining; in some cases the vertex clouded, leaving a median longitudinal reddish line from which six or seven very fine reddish transverse lines run toward each eye; eyes reddish brown. *Rostrum*, length 2.28 mm., reaching to posterior margins of hind coxae, yellowish brown, extreme apex fuscous.

Antennae: segment I, length .74 mm., yellowish brown tinged with fuscous; II, 2.25 mm., black with a very narrow yellow ring at the base; III, 1.34 mm., fuscous: IV, .8 mm., fuscous; all the segments clothed with very fine pubescence.

Pronotum: length 1.19 mm., width at base 1.96 mm., width at anterior angles .88 mm., collar .71 mm.; yellowish brown with two conspicuous black rays on the disk, frequently covering the outside half of the calli and running back to near the posterior margin of the pronotum; sides with blackish up to the height of the coxal cleft, this color extending back on the pleura. *Scutellum* yellowish brown, in some cases rather pale, tinged with pink on the margins. *Sternum* blackish on the sides, margined with brownish red, paler on median ventral part; prosternal xyphus yellowish like the coxae.

Hemelytra: greatest width 2.4 mm.; yellowish pubescence rather prominent; clavus and corium dark brown to fuscous, tinged with reddish; embolium except the apex, and narrow margin of the corium, lighter yellowish brown; cuneus pale tinged with yellowish, clothed with prominent fine pubescence. *Membrane* fuscous except the veins and a narrow margin bordering them; a spot just beyond the apex of the cuneus pale to yellowish.

Legs: coxae pale to yellowish, with reddish on the sides at the base; femora pale brownish yellow, apical two-thirds of the posterior femora reddish brown with two pale rings often evident near the apices, the middle pair in some cases with a touch of red on the ventral side toward the apices.

Venter: brownish black with reddish along the dorso-lateral margin, in some specimens almost entirely reddish; genital segment shining, a brownish red paler area on each side of the ventral median line, a tubercle on the posterior corner of the dorso-lateral margin just above the base of the left clasper; genital claspers yellowish brown and prominent, the left clasper (fig. 208) divided into two major parts near the base.

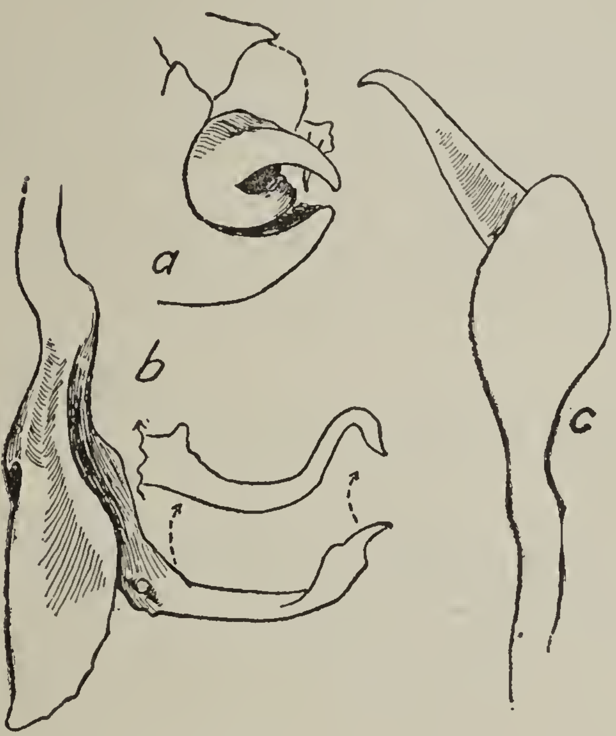

FIG. 208. LYGUS LAUREAE, MALE GENITAL CLASPERS

a, Genital segment, left lateral aspect (not to scale); b, left clasper, dorsal aspect; c, right clasper, ventral aspect

♀. Length 6.4 mm., greatest width 2.6 mm.; similar to the male but slightly more robust and everywhere with more reddish; sides of the thorax and venter with more reddish than fuscous.

Holotype: ♂ July 4, 1915, Four Mile, New York, altitude 2700 feet (H. H. Knight).

Allotype: with the type.

Paratypes: 250 ♂♀ taken with the type. 18 ♂♀ June 21–30, Black Mountains, North Carolina (Beutenmuller). ♂ ♀ August 4, Aurora, West Virginia (O. Heidemann). ♂ June 18, West Point, New York (Wm. T. Davis). ♂, Lake Toxaway, North Carolina (Mrs. A. T. Slosson).

The species breeds on mountain laurel (*Kalmia latifolia*), and has a life history very similar to that of *communis* and of *invitus*. On June 10, 1915, at Four Mile, New York, the fifth-stage nymphs were found to be plentiful on laurel. The nymphs are yellowish green to pink in color and many individuals are more orange in the fifth instar. The unfolding flower clusters furnish food and shelter for the developing nymphs, where they feed in preference to the leaves if the plant puts forth flowers. In 1916, at Four Mile, the laurel did not bloom as plentifully as in 1915, and the bugs were much less abundant. The first adult obtained in 1915 emerged on June 13, being reared on laurel leaves and flowers kept in a bottle. The eggs are doubtless deposited in the twigs of laurel during July, and hatch in the following spring with the unfolding of the leaves. This most unusual and interesting species will doubtless be found breeding on laurel thruout the Appalachian region.

Lygus carolinae Reuter

1876 *Lygus carolinae* Reuter
Caps. Amer. bor., p. 71.

This species and *fasciatus* are the only forms of Lygus described from the United States by Reuter which the writer, as well as other workers, has been unable to locate. It is very probable that when considerable collecting is done in the southern Appalachian region, these two species will be found. Judging by the number of new species found in New York and the New England States, it will not be surprising if a few more new forms are taken along with the collecting necessary to find *carolinae* and *fasciatus*.

The following is a liberal translation from the original latin description:

Oblong-ovate, greenish, minutely punctured above, pale pubescent, antennae testaceous, fuscous toward the apex, second segment longer than the width of the pronotum at base; scutellum with two longitudinal fuscous stripes; hemelytra immaculate, cuneus with the base fuscous, its apex broadly black; abdomen black above; apices of the femora annulated with fuscous, apices of the tarsi black; tibiae impunctate testaceous; membrane marked with fuscous, veins greenish. Length $5\frac{1}{3}$ mm. Hab. Carolina.

EUROPEAN SPECIES OF LYGUS SUPPOSED TO OCCUR IN THE UNITED STATES

The following European species have been recorded from North America by the leading workers in Hemiptera: *Lygus contaminatus* Fallén, *Lygus lucorum* Meyer-Dür, *Lygus viridis* Fallén.

The writer has been able to study, in the United States National Museum, European material of each of the above species which was determined by Reuter and sent over to Mr. Heidemann. After studying all the important collections of Lygus from this country, the writer feels confident that the above species have not been taken in North America and that the records were based on misidentifications. The record for *Lygus viridis* Reuter (1909) from New Hampshire was based on two specimens, which are here included with *Lygus alni* and are shown to differ from the European *viridis* Fallén. *Lygus lucorum* was recorded from this country by Uhler and *Lygus contaminatus* by both Provancher and Uhler. The records were doubtless based on specimens of *Lygus apicalis*, which in certain color phases very much resembles *lucorum* and *contaminatus*. Mr. Van Duzee's recent records of *contaminatus* from California were based on a form of *apicalis*, specimens of which the writer has dissected and compared with our eastern form and found not to differ structurally.

SPECIES THAT HAVE BEEN INCORRECTLY PLACED IN THE GENUS LYGUS

Plagiognathus guttatipes (Uhler)

1895 *Lygus guttatipes* Uhler
Hemip. Colo., p. 35.

There is in the Uhler collection, now at the United States National Museum, a representative of this species which agrees with the description of *guttatipes* and is doubtless of the type material. The male genital characters, as well as certain other points given in the original description, show the species to be a Plagiognathus.

?Lygidea annexus (Uhler)

1872 *Lygus annexus* Uhler
U. S. Geol. Surv. Terr., Montana, Prelim. rept., p. 413.

The types of this species are in the United States National Museum, two males and one female, labeled *N. E. Colo.* The writer has also seen other specimens of the species from Colorado. An examination of the male genitalia, combined with other characters, shows it to be congeneric with *Lygidea rubecula* Uhler. There is considerable doubt as to whether these species belong to the genus Lygidea, this being a point that can be settled only after further study and examination of the type species.

Phytocoris vividus (Uhler)

1895 *Lygus vividus* Uhler
Calif. Acad. Sci., Proc. 2d ser:**4**:260.
1910 *Dichrooscytus marmoratus* Van Duzee
Amer. Ent. Soc., Trans. **36**:78.
1912 *Phytocoris vanduzei* Reuter
Hemip. miscellen, p. 30.

There are specimens of this species in the Uhler collection, coming from southern California, which evidently represent type material. The writer has compared a paratype of *Dichrooscytus marmoratus* Van Duzee with *Lygus vividus* Uhler and is unable to distinguish between the two. The type material has faded somewhat, due to aging, but the male genital claspers are very distinctive and are undoubtedly specific.

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